9

EXPERIMENTS

AND

OBSERVATIONS

MADE

With the VIEW of IMPROVING the ART of COMPOSING and APPLYING

CALCAREOUS CEMENTS, &c.

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CONTENTS.

A SECTION

SECTION IV.

SECTION V.

SECTION VI.

SECTION VII.

SECTION

SECTION VIII.

SECTION IX.

SECTION X.

SECTION XI.

SECTION XII.

SECTION XIII.

SECTION XIV.

SECTION XV.

SECTION

SECTION XVI.

SECTION XVII.

SECTION XVIII.

SECTION XIX.

SECTION

SECTION XX.

SECTION XXI.

SECTION XXII.

SECTION

SECTION XXIII.

SECTION XXIV.

SECTION XXV.

SECTION

SECTION I.

AMONGST the inſtances and experiments produced in my public Courſes of Chemiſtry in 1774, to illuſtrate my notions of the polarity of matter, divers mixtures of lime ſand and water, were particularly conſidered: and theſe being preſerved and methodically arranged, according to the plan of this ſchool, ſoon ſuggeſted to me an enquiry which I have proſecuted with great attention ever ſince that time.

As the ſtrength and duration of our moſt uſeful and expenſive buildings depend chiefly on the goodneſs of the cement with which they are conſtructed, I looked to the improvement of mortar as a ſubject of great importance, in this country particularly, where the weather is ſo variable and trying, and the mortar commonly uſed is ſo bad,

that the timbers of houſes laſt longer than the walls, unleſs the mouldering cement be frequently replaced by pointing. - But ſeeing that many years are requiſite for the greateſt degree of induration which cementitious mixtures like mortar can acquire, or for our diſcovering the imperfections of them; and that the life of man is too ſhort to allow any conſiderable improvements of them to be derived from ſuch experiments as had hitherto been made, I reſolved in the beginning of the year 1775 to inveſtigate more cloſely than I had hitherto done, the principles on which the induration and ſtrength of calcarious cements depend; not doubting that this would lead me by an untried path to recover or to excel the Roman cement, which in aqueducts and the moſt expoſed ſtructures has withſtood every trial of fifteen hundred or two thouſand years.

SECTION

SECTION II.

Experiments and Obſervations on Lime-ſtone and Lime.

I Had already learned from the chaſte and philoſophic productions of Dr. Black, that calcarious ſtones which burn to lime, contain a conſiderable quantity of the elaſtic fluid called fixable air or acidulous gas, which in combination with the earthy matter forms a great part of the maſs and weight of theſe ſtones; and that the difference between lime-ſtone or chalk and lime, conſiſts chiefly in the retention or expulſion of this matter.

EXPECTING to learn ſomething further relative to lime, and particularly, to diſcover the cauſe of the differences which appear in cements made with different kinds of lime, I made the following experiments.

I PROCURED ſpecimens of different kinds of lime-ſtone and chalk, and breaking them

into ſmall fragments, I burned them in crucibles lined with lime: to prevent the pieces from touching their crucibles and vitrifying at thoſe ſurfaces which lay next to them: I likewiſe burned the like ſpecimens in crucibles perforated to admit a free current of air through them; and laſtly, I expoſed three pounds of either ſpecimen to a graduated fire in an earthen retort which was barely ſufficient to hold this quantity, and whoſe neck I lengthened by fitting to it a glaſs conical tube luted at the juncture with four parts of lime one of fine ſand and as much diſſolved glue ſuch as the carpenters uſe, as was ſufficient to form a paſte; having found this luting to hold faſt and to be impervious to any elaſtic fluid or liquor expelled in ſuch proceſſes. I immerſed the extremity of the glaſs tube in mercury, and inverting a bottle filled with mercury over the extremity of the tube, I received whatever water or elaſtic fluid was expelled from the calcarious ſtones by the fire, and I meaſured the quantity of theſe by inſtantly applying a freſh bottle as ſoon as the former was filled. When all the water was expelled, or when I knew the quantity of it contained in the lime-

lime-ſtone or chalk, I uſed a baſon of water and bottles filled with water, making allowance for the matter imbibed by the water.

To avoid a tedious detail of particulars which do not immediately relate to the chief object of this eſſay, I ſhall only mention ſummarily the moſt pertinent obſervations which theſe and other experiments afforded; endeavouring that the terms in which I ſhall deliver theſe obſervations ſhall deſcribe the experiments ſufficiently for thoſe who are acquainted with modern chemiſtry.

OBSERVATION I.

LIME-STONE or chalk heated only to redneſs, in a covered crucible, or in a perforated crucible through which the air circulates freely, looſes only about one-fourth of it's weight, however long this heat be continued. The ſort of lime ſo formed effervesces conſiderably in acids, ſlakes ſlowly and partially to a powder which is not white, but is grey or brown, and heats but little in ſlaking.

IN deſcribing heats I do not regard the heat in particular parts of the fuel, but

only that which the bodies themſelves are made to conceive equally through their whole maſs, whether they be in veſſels which defend them conſiderably from the action of the fire, or fully expoſed to it by their immediate contact with the fuel.

Observation. 2.

Lime-stone or chalk expoſed to a heat barely ſufficient to melt copper, whether in a perforated crucible or otherwiſe, loſes about one third of its weight in twelve hours, and very little more in any longer time. This lime effervesces but ſlightly in acids; it heats much ſooner and more ſtrongly than the foregoing, when water is ſprinkled on it, and it ſlakes more equably and to a whiter powder. In a variety of trials, this lime appeared to be in the ſame ſtate with the beſt pieces of lime, prepared in the common lime-kilns. For the quantities of acidulous gas obtainable from both by a ſtronger heat, or in ſolution, were nearly equal; they ſlaked in equal times, with the ſame phenomena, and to the ſame colour and condition of the powder.

Obser-

OBSERVATION. 3.

THE lime burned in perforated crucibles, or in the naked fire, is whiter than that burned in common crucibles covered, in which caſe the air has not ſo free acceſs to it; altho' the loſs of weight be the ſame in both; but this latter kind of lime, in ſlaking, affords as white a powder as any other which has loſt equally of its weight. Whatever portion of phlogiſton it retains to produce this duſky colour, is either detached in the ſlaking, or does not ſenſibly affect the lime in any uſe, to which I applied it.

OBSERVATION. 4.

WHEN dry chalk or lime-ſtone is uſed, in the proceſs above deſcribed for making lime in cloſe veſſels, and for examining the matter which is expelled by fire, the quantity of water obtainable from it by any heat, is ſo inconſiderable as to deſerve no notice in our menſuration of that matter.

OBSERVATION. 5.

CHALK or lime-ſtone heated gradually in theſe cloſe veſſels, loſes very little acidulous gas until it begins to redden: after this the

elaſtic fluid iſſues from it the quicker as the heat is made greater, and continues to iſſue until the retort glows with a vivid white heat ſufficient to melt ſteel.

OBSERVATION. 6

FORTY-EIGHT ounces of chalk yield twenty-one ounces of elaſtic fluid, the firſt portions of which are turbid as they iſſue, but ſoon become clear without loſs of bulk, by the condenſation of the watery vapour: the remaining portions iſſue tranſparent and inviſible. One thirty-ſixth of this elaſtic fluid, and ſometimes much more of it, is phlogiſtic air, the remainder is pure acidulous gas.

OBSERVATION. 7

THE reſiduary lime of forty-eight ounces of chalk, urged with ſuch heat to the total expulſion of the elaſtic fluids, weighs only twenty-ſeven ounces, whilſt it is red hot. When it cools it weighs more by reaſon of the air which it imbibes as the fire eſcapes from it.

OBSER-

Observation 8.

When no more heat is employed than is neceſſary for the expulſion of theſe elaſtic fluids, the reſiduary matter is found contracted ſenſibly in volume, and is good lime, tho' not ſo white as lime prepared in the uſual way. With water it ſlakes inſtantly, grows hiſſing hot and perfectly white. The ſlaked powder is exceedingly fine, except in thoſe parts of the lime which lay in contact with the retort, which are always ſuperficially vitrified, becauſe clay and lime promote the vitrification of each other.

Observation 9.

The lumps of this lime, immerſed in lime-water, or boiling water, to expel the air which ſuch ſpongy bodies imbibe in cooling, diſſolve in marine acid without ſhewing any ſign of effervescence.

Observation 10.

Lime-stone or chalk gradually heated in a crucible, or on the bed of a reverberatory furnace, or in contact with the fuel in a wind furnace, does not become perfectly noneffervescent and ſimilar to the lime laſt deſcribed

ſcribed, in ſlaking inſtantly, and growing hiſſing hot when water is ſprinkled on it, until it has, after a ſtrong red heat of ſix or eight hours, ſuſtained a white heat for an hour or more. I underſtand by a white heat, that which is ſufficient to melt caſt iron compleatly.

Observation. 11.

Lime-stones heated ſufficiently to reduce them to lime which ſlakes inſtantly with the ſigns above deſcribed, and which is perfectly nonefferveſcent, do not in general loſe ſo much of their weight as chalk-ſtone does, under the like treatment. Some lime-ſtones loſe little more than a third of their weight. Thoſe which loſe the moſt, ſlake the quickeſt and to the fineſt powder; and thoſe which loſe the leaſt, ſlake the ſloweſt and to a gritty powder compoſed of true lime and particles chiefly gypſeous.

Observation. 12.

The quantity of gypſum, or of other earthy matter in well burned lime, is diſcoverable by weak marine acid; for this diſſolves and

and waſhes away the lime, leaving the gypſum to be meaſured when dry, the part of the gypſum which diſſolves being too ſmall to deſerve any attention; and if any other earthy matter or any ſaline matter exiſted in the lime-ſtone, it vitrifies with part of the calcarious matter in the heat neceſſary for making nonefferveſcent lime, and is ſeparable by the means laſt mentioned, and even by a fine ſieve in moſt inſtances.

Observation. 13.

When lime-ſtone or chalk is ſuddenly heated to the higheſt degree above deſcribed, or a little more, it vitrifies in the parts which touch the fire veſſels, or furnace, or fuel, and the whole of it becomes incapable of ſlaking freely or acting like lime. Lime-ſtone is the more apt to vitrify in ſuch circumſtances, as it contains more gypſeous or argillaceous particles; and oyſter-ſhells or cockle-ſhells vitrify more eaſily than lime-ſtone or chalk, when they are ſuddenly heated; which I impute to their ſaline matter; for when they are long weathered, they do not vitrify ſo eaſily.

Obser-

OBSERVATION. 14.

THE agency of air is no further neceſſary in the preparation of lime, than as it operates in the combuſtion of the fuel.

OBSERVATION. 15.

CALCARIOUS ſtones acquire the properties of lime in the moſt eminent degree, when they are ſlowly heated in ſmall fragments until they appear to glow with a white heat, when this is continued until they become noneffervescent, but is not augmented. The art of preparing good lime conſiſts chiefly in theſe particulars.

OBSERVATION 16.

THAT lime is to be accounted the pureſt and fitteſt for experiment, whether it be the beſt for mortar or not, which ſlakes the quickeſt and heats the moſt in ſlaking, which is whiteſt and fineſt when ſlaked, which when wetted with lime-water diſſolves in marine acid or diſtilled vinegar without effervescence, and leaves the ſmalleſt quantity of reſiduary undiſſolved matter.

OBSER-

OBSERVATION 17.

THE quick ſlaking, the colour of the ſlaked powder, and the former acid, are the moſt convenient, and perhaps the beſt teſts of the purity of lime. The whiteneſs denotes the lime to be free from metallic impregnation; the others ſhew any imperfections in the proceſs of burning, and the heterogeneous matter inſeparable from the calcareous earth by burning.

SECTION

SECTION III.

Remarks on the Phlogiſticated Air which appeared in ſome of the foregoing Experiments.

As phlogiſticated air had not been noticed in any experiment heretofore made on chalk or lime-ſtone, I reſolved to examine the elaſtic fluid detached from them in the uſual method.

I extricated ſeveral gallons of elaſtic fluid from chalk, during the ſolution of it in marine acid diluted largely with water; and after agitating this elaſtic fluid with the neceſſary quantity of water, and ſometimes with lime-water, until all the acidulous gas was imbibed by them, I found a reſidue conſiſting of common air, which was about one twenty-eighth of the bulk of the acidulous gas, in ſome trials, in others it was much leſs.

As I have not had time to examine lime-ſtones in the ſame manner, or to proſecute this

this ſubject by other experiments, and as it does not appear ſufficiently intereſting in our preſent enquiry concerning calcareous cements, I muſt content myſelf with offering a conjecture concerning it.

THE air which is extricated during the ſolution of chalk, ſeems to be that which chalk, like other porous bodies, imbibes by capillary attraction; and it retains its proper character, becauſe all the phlogiſtic matter of chalk is held in the ſolution. It may happen likewiſe that ſome air eſcapes from the water whilſt it imbibes the acidulous gas, which it attracts more forcibly; and this air from the water may contribute to the bulk of that which appears in the ſolution of calcarious bodies. But whilſt chalk is deprived of its acidulous gas by the action of fire, the air which was held in its pores, and which attracts phlogiſton, is expelled in combination with phlogiſton, and conſequently in the form of phlogiſtic air; and the air contained in the pores and in the cavity of the retort, contributes to the bulk of the phlogiſtic air obtainable in this manner.

THIS

This conjecture appears the more probable when we conſider, that the quantity of air imbibed by porous bodies is much greater than it appears in any experiments made with the air pump; as I ſhewed in my public courſe of chemiſtry in 1776, by the great increaſe of weight, which red hot charcoal acquired in cooling in veſſels into which nothing ponderable but air was admitted. The ſame attractive powers which draw air into bodies, and condenſe it in them, reſiſt the expanſion and eſcape of it in the void: and detain, in ſuch a ſituation of the bodies, that quantity, whoſe repulſive powers are counterpoiſed by the attractive powers.

SECTION

SECTION IV.

Experiments ſhewing that Lime is better for Mortar as it retains leſs acidulous Gas, and ſhewing ſome of the Cauſes of the Imperfection of common Mortar.

ON divers conſiderations it appeared to me, that the perfection of lime for mortar conſiſts chiefly in the total expulſion of the acidulous gas; but to be better ſatisfied of the truth of this opinion, I made ſeveral parcels of mortar, the deſcription of which will be abridged by obſerving in this place concerning all of them, that the ſand employed was coarſe Thames ſand, ſuch as I uſe in my ſand baths; that the lime was ſlaked as ſoon as it cooled after being burned, and with the ſmalleſt quantity of water neceſſary for this purpoſe; that it was ſifted through a fine braſs wired ſieve as ſoon as it was fully ſlaked; and that each parcel of mortar was beaten and briſkly formed with the quantity of water which was barely ſufficient to give it the uſual conſiſtence, which

10.

Sand, — — — 6
The foregoing lime, — 1
Water, q. ſ.

11.

Sand, — — 3
Imperfect chalk lime deſcribed in obſ. 1, ſect. 2, — — 1
Water, q. ſ.

12.

Sand, — — 6
The laſt mentioned lime — 1
Water, q. ſ.

THE lime of the 9, 10, 11, and 12 ſpecimens was ſlaked whilſt it was hiſſing hot, in a covered veſſel; becauſe it would not ſlake ſufficiently when it was ſuffered to cool before the water was ſprinkled on it, or when it's heat was ſoon diſſipated by a free expoſure to the air and haſty evaporation of the water: And as this lime required ſeveral hours to ſlake, I put it into a bottle as ſoon as it was cool, and kept it well ſtopped for twenty-four hours before I ſifted it.

At

At the ſame time I made two ſpecimens of mortar with common chalk lime and ſand in the foregoing manner.

Each ſpecimen was ſpread as ſoon as it was made, to the thickneſs of half an inch on a plain tile previouſly ſoaked in water; the tiles were numbered and kept cloſe by each other in an airy part of my elaboratory until the mortar was dry, and then they were equally expoſed, ſtanding upright, in a place where the air ſun and rain had free acceſs to them.

In the courſe of fourteen or fifteen months theſe ſpecimens afforded me a great deal of information, which will be noticed in due time; even in the firſt ſix months they ſhewed me clearly that lime is the better for mortar as it is more perfectly freed from acidulous gas. For when the compariſon was made between ſpecimens of mortar conſiſting of the ſame quantities of lime and ſand, I found that the mortar made with well burned non-effervеſcent lime, hardened ſooner and to a much greater degree, than mortar made with common lime or my ſtone or chalk lime

burned in the manner expreſſed in the ſecond obſervation of the ſecond ſection; and the ſpecimens made with the ſtone or chalk lime which was leaſt burned, were incomparably worſe than any of the others; for they never acquired any conſiderable hardneſs, and they mouldered in the winter, the ſooner as they contained more of the lime and cracked more in drying.

I obſerved that the ſpecimens which contained the ſmaller quantities of well burned lime cracked much leſs than the others, or not at all; that they adhered to the tiles more firmly, and were leſs injured by freezing; but as the ſpecimens made with an exceſs of the beſt burned lime were not more cracked than thoſe made with equal quantities of the other kinds of lime, and as I could diſtinguiſh the imperfections ariſing from the exceſs of lime, from thoſe which proceeded from the bad quality of it, I was ſatisfied that the lime which is moſt compleatly burned is the beſt for mortar.

Considering the heat, which I found neceſſary to extricate the laſt portions of acidulous gas from chalk or lime-ſtone, to be much greater

greater than what is ever excited in making lime in this country or elſewhere, ſo far as I had obſerved or could learn from others; I ſuſpected that the lime commonly uſed in building is ſeldom or never ſufficiently burned.

On repeated trials of ſeveral ſpecimens of ſuch lime, I found this ſuſpicion to be well founded, for they all effervesced and yielded acidulous gas, more or leſs, during the ſolution of them, and ſlaked ſlowly in compariſon with well burned lime.

To render the effervesence conſpicuous, a ſtrong acid ought to be uſed, becauſe the quantity of water in a diluted acid, retains a proportional ſhare of the acidulous gas, and a certain quantity will retain the whole of it, and prevent the effervesence; becauſe the effervesence depends on the eſcape of the elaſtic fluid out of the ſolution. This is exemplified in the mixture of diluted vitriolic acid with the diluted ſolution of ſalt of tartar, lately recommended as a medicine by Dr. Hulme: for theſe ſolutions mix without effervesence; although a more concentrated ſolution of the

alkali mixed with vitriolic acid effervesces violently.

By several experiments, the relation of which is not necessary for those who are instructed in chemistry, and would be uninteresting to others, I found that the chalk lime used in London, when taken as fresh as it can be had at the lime-wharf near Blackfriars-bridge, consists of pieces which being the best burned contain, especially in their central parts, about one-twentieth of their weight of acidulous gas; of others which contain more; and of others which retain near half their original quantity; that these last are easily discoverable by their specific gravity and hardness; and that this is the part of our common lime, which slakes the latest and of the duskiest colour, or which never slakes at all.

On a peck of this lime I sprinkled water, endeavouring to slake it equably by throwing the most water on those pieces which required it most. After the lime had stood a quarter of an hour, to slake, I sifted it through a sieve whose apertures were squares of one sixteenth

ſixteenth of an Inch; and then meaſuring the part which could not paſs through the ſieve, I found it to be about one fifth part of a peck.

I ſprinkled boiling water on this coarſe part, and put it in a cloſe veſſel in a warm place to accelerate the ſlaking of it.

I made a parcel of mortar with one part of the ſifted lime and three of ſand with a ſufficient quantity of water; and another parcel with one part of the lime ſix of ſand and the neceſſary quantity of water; and I tried them upon tiles in the manner already related, in the month of April, the weather being dry.

The foregoing coarſe portion of the lime, after three hours, was ſlaked in ſeveral parts to a greyiſh powder, and I could perceive that more of it would ſlake in a longer time. I anticipated this by reducing the unſlaked part to powder and mixing them together.

With this powder and ſand and water in the foregoing proportions I made two ſpecimens of mortar, and expoſed them as I had done by the former.

In a few months it appeared that the ſpecimens laſt mentioned ſcarcely deſerved the name of mortar; whilſt thoſe made with the firſt ſlaked part of the lime, were but little inferior to the beſt ſpecimens made with the ſame proportions of chalk lime and ſand.

These experiments confirmed me in the opinion that lime is the better for mortar as it is freer from acidulous gas; they ſhewed one of the cauſes of the badneſs of our common mortar; and how to manage ill-burnt lime, when better cannot be had.

The workmen uſually ſlake the lime mixed with the ſand or gravel in great heaps, and do not ſkreen it until the moſt uſeful part is debaſed by that which ſlakes after five or ſix hours or more, and which is little better than ſo much powder of chalk. But if they would ſkreen the lime in about half an hour

hour after the water is thrown on it, the mortar would be much better, although the quantity of lime in it ſhould be much leſs; for I obſerved in all the foregoing ſpecimens, that thoſe which contained the ſmalleſt quantity of lime were the beſt; and this quantity is much ſmaller than is uſually employed in making mortar.

THESE remarks are applicable to mortar made with ſtone-lime; though the ſtone-lime be generally better than the chalk-lime uſed in London, becauſe they are obliged to burn it better, as it will not ſlake otherwiſe.

In the brief relation of theſe experiments I have taken no notice of the flint kernels which frequently occur in chalk-lime, or of the other ſtoney maſſes different from the calcarious, which are found in lime-ſtone; becauſe I took care that they ſhould not lead me into any errors.

WHEN firſt I noticed the quantity of chalk-lime which ſlakes lateſt or not at all, I ſuſpected that this difference might in ſome degree be owing to the admixture of argillaceous

or

or other matter; but on trying these parts in acids, and after burning several specimens of them, I was convinced that the only impediment to their slacking consisted in their not being sufficiently burnt in the kiln.

SECTION

SECTION V.

Experiments ſhewing how quickly lime imbibes acidulous gas, and is injured by Expoſure to Air: Practical Inductions, &c.

IT was already known that lime expoſed to air gradually loſes thoſe characters which chiefly diſtinguiſh lime from whiting or powder of chalk, and that it reſumes the acidulous gas which had been expelled from it in burning. But as I was deſirous to know in what meaſure or time theſe changes take place, and in what circumſtances they are accelerated or retarded, I made the following Experiments.

On the 22d of Auguſt 1776 I expoſed two pounds avoirdupoiſe of well-burned noneffervescent chalk lime, in fragments of the ſize of a walnut ſpread on a board, in a dry unfrequented room. I expoſed the ſame quantity of this lime, at the ſame time and in the ſame manner, in a paſſage through which there was a conſtant current of air; and I put

put the ſame quantity of this lime, in fragments of the ſame ſize, in a box which might hold as much more of it, and placed the box looſely covered with its lid, cloſe by the firſt portion of lime.

In 24 hours the ſuperficial lumps of the firſt parcel cracked in ſome parts a little, thoſe of the ſecond cracked more, thoſe of the third were not viſibly altered. In forty-eight hours the firſt parcel cracked ſo much as to fall into ſmaller fragments on being moved, and theſe were reducible to powder by preſſing them between the fingers: The ſecond parcel underwent the like or rather a greater change, for it was more cracked and friable: The third now begun to crack in the ſuperficial parts.

On weighing them, I found that the firſt parcel weighed two pounds five ounces, the ſecond two pounds ſix ounces and one drachm, the third two pounds one ounce ten drachms: I then returned them to their former ſtations.

 In

In ſix days the firſt parcel weighed two pounds ten ounces ſeven drachms; the ſecond two pounds twelve ounces one drachm; the third two pounds four ounces eight drachms.

In twenty-one days the firſt parcel weighed three pounds one drachm; the ſecond three pounds two ounces one drachm and a half; the third two pounds ſix ounces eight drachms.

During this increaſe of weight the fragments ſplit into ſmaller pieces, but did not fall into powder, except in a ſmall part of them, or when they were handled.

By ſimilar experiments made on well burned ſtone lime I found that this imbibes matter from the air nearly in the ſame manner as chalk lime, but rather more ſlowly; which I think is owing to its cloſer texture.

On expoſing common chalk or ſtone lime in the ſame way, I find that it increaſes in weight much leſs and more ſlowly.

To

To discover the quantity of water which the lime imbibed from the air, and which contributed to this increase of weight, I put each parcel in a glass retort; and adjusting to it my apparatus whereby all that is condensible is saved, whilst elastic fluids are at liberty to escape, I found that the quantity of water contained in each parcel of lime, was nearly in some, and in others accurately one-twenty-fourth of the gained weight, the remainder of the weight gained was of acidulous gas mixed with a little air, which latter I do not reckon, because it was already weighed in the lime.

If a glass bottle be filled with fragments of well-burned chalk lime, or stone lime, or shell lime, and well stopped with a ground glass stopple slightly waxed where it fits the neck of the bottle, the lime will remain unaltered in weight, or in any other known particular, for a year or two; as I have repeatedly experienced: even the phosphorescence of lime is thus preserved in its full lustre, for a year or more.

Thus it appeared that well burned lime

imbibes acidulous gas from the air, the ſooner as it is the more fully expoſed to it: that lime imbibes this matter from the open air, the more greedily as it is more perfectly deprived of it previous to the expoſure: that lime cannot be long preſerved unaltered in any veſſels which are not perfectly air-tight, but may be kept uninjured for any time in air-tight veſſels filled with it: that chalk lime, by reaſon of its ſpongineſs, or by ſome other condition of it, requires to be kept leſs expoſed than ſtone lime, and well burnt lime leſs expoſed than common lime, to render the depravation of them equal in equal times: that if acidulous gas imbibed by lime previous to its being uſed in mortar, be as injurious to the mortar, as the acidulous gas retained in equal quantity by ill-burned lime is, lime grows the more unfit for mortar every hour that it is kept expoſed to air, whether in a heap, or in caſks pervious to air.

I THINK moreover that theſe experiments ſhew that lime undergoes theſe changes by expoſure, much quicker than has been ſuſpected; ſince well burned chalk lime kept in

a dry room, imbibes near a pound of acidulous gas in three weeks, in the ſummer ſeaſon.

NOT to truſt to theory what I could prove by experiment, I did not reſt ſatisfied with the obſervations and reaſons which might perſuade one that lime, which has imbibed ſome acidulous gas, is as unfit for the uſes now under conſideration, as lime which retains an equal quantity of the like matter by reaſon of the deficiency of heat in burning it.

I TRIED parcels of well burned chalk and ſtone lime, ſome of which were uſed freſh, others expoſed two days, others ſix days, others twenty-one days, in the ſame circumſtances; by making ſeveral ſpecimens of mortar with them, and expoſing the ſpecimens in the manner already related: and in a few months I was ſatisfied that the ſpecimens made with freſh lime were the hardeſt and beſt, and that the others were worſe as the lime of them had been longer expoſed: for thoſe made with the lime which had been expoſed three weeks and had gained four or five ounces to each pound, were ſo eaſily

eaſily cut or broke, ſo much affected by moiſture and drying, and ſo liable to break off from the tiles, as to be utterly unfit for the ordinary uſes of mortar.

AFTER this there remained no doubt that lime grows worſe for mortar every day that it is kept in the uſual manner in heaps or in crazy caſks; that the workmen are miſtaken in thinking that it is ſufficient to keep it dry; that lime may be greatly debaſed without ſlaking ſenſibly; and that the ſuperficial parts, of any parcel of lime, which fall into ſmall fragments or powder without being wetted, and merely by expoſure to air, are quite unfit for mortar; ſince this does not happen until they have imbibed a great deal of acidulous gas.

I NOW ſaw more clearly another cauſe of the imperfection of our common cements. The lime being expoſed a conſiderable time before it is made into mortar, and drinking in acidulous gas all the while, the quicker as it is the better burned, is incapable of acting like good lime, when it is made into mortar; and often approaches to the condition of whiting, which with ſand and water makes

a friable periſhable maſs, however carefully it be dried. In London particularly they uſe lime which is burned, at the diſtance of ten or twenty miles or more, in Kent and elſewhere, with an inſufficient quantity of fuel. This lime remains in the kiln, to which the air has acceſs, for many hours after it is burned. It is expoſed for ſome days in the tranſportation, and on the lime-wharfs; and it undergoes further expoſure and carriage before the artiſt ſlakes it for mortar. It is no wonder that the London mortar is bad, if the imperfection of it depended ſolely on the badneſs of the lime; ſince the lime employed in it, is not only bad when it comes freſh from the kiln, but becomes worſe before it is uſed, and when ſlaked is as widely different from good lime, as it is from powdered chalk.

SECTION

SECTION VI.

Experiments and Obſervations made to determine whether Mortar be the better for being long kept before it is uſed.

I AM generally diſpoſed to think that there is ſome good reaſon for any practice which is common to all men of the ſame trade, although it may not be eaſily reconcilable to the notions of others: and ſeeing that the builders ſlake a great quantity of lime at once, more than they can uſe for ſome days, and that all thoſe, whom I converſed with, eſteemed mortar to be the better for being long made before it is uſed; and that plaiſterers particularly follow this opinion in making their finer mortar or ſtucco for plaiſtering within-doors; I was deſirous to diſcover the grounds of theſe meaſures ſo repugnant to the notions gathered from the foregoing experiments and others.

In the month of March 1777 I made about a peck of mortar, with one part of the freſheſt

freſheſt and beſt chalk lime ſlaked, ſix parts of ſand, and water q. ſ; for in a great number of experiments, I obſerved that this proportion of lime was better than any larger which I had tried, or which the workmen obſerve in making mortar.

I FORMED the mortar into an hemiſpherical heap on the paved floor of a damp cellar, where it remained untouched twenty-four days. At the expiration of this time, I found it hardened at the ſurface; but moiſt, and rather friable or ſhort than plaſtic in the interior parts of it.

I BEAT the whole of it with a little water to its former conſiſtence; and with this mortar and clean new bricks, I built a wall eighteen inches ſquare and half a brick in thickneſs, in a workman-like manner. On the ſame day I made mortar of the ſame kind and quantities of freſh chalk lime and ſand, tempered in the ſame manner; and I built a wall with it, like the former, near it, and expoſed equally to the weather.

I EXAMINED the mortar in the joints of theſe walls every fortnight, by picking it with a pointed knife, and could perceive a very conſiderable difference in the hardneſs of them; the mortar which was uſed freſh being invariably the hardeſt.

AT the expiration of twelve months, in pulling theſe walls to pieces, and by ſeveral trials of the force neceſſary to break the cement and ſeparate the bricks, I found the mortar which had been uſed quite freſh, to be harder and to reſiſt fracture and the ſeparation of it from the bricks, in a much greater degree than the other ſpecimen.

CONSIDERING that mortar expoſed in the foregoing manner, muſt imbibe ſome acidulous gas, though not ſo much, perhaps, as the dry and ſpongy lumps of lime drink in, during the ſame time; that the additional quantity of water neceſſary in beating it up the ſecond time, muſt have introduced more of the like matter, as all native waters contain ſome quantity of it; that the freſh expoſure in the laſt mentioned agitation of the mortar muſt have contributed ſomething to the ſame

effect; and laſtly that the event of this experiment coincided with the notions already derived from others; I concluded that mortar grows worſe every hour that it is kept before it is uſed in building, and that we may reckon as another cauſe of the badneſs of common mortar, that the workmen make too much at once, and falſly imagine that it is not the worſe but better for being kept ſome time.

HAVING in conſequence of theſe obſervations had a great deal of converſation with workmen on this ſubject, I could perceive the origin of this error.

SOME portions of every kind of lime uſed in this country, do not ſlake freely, by reaſon of their not being ſufficiently burned, or of the admixture of gypſeous or argillaceous matter; and theſe, like marle, ſlake in time, though not ſo quickly as the purer lime.

THE plaiſterers, who uſe a finer kind of mortar made of ſand and lime, obſerve that their plaiſter or ſtucco bliſters, when it contains

tains ſmall bits of unſlaked lime; and as their purpoſe is to work their ſtucco to a ſmooth ſurface, and to ſecure it from cracking, or any ſuch roughneſs as would be occaſioned by the ſlaking or mouldering of bits of calcareous matter in the face of it; and as the hardneſs of the ſtucco is not their chief object; they very properly keep their mortar a conſiderable time before they uſe it, to the end that the bits of imperfect lime, which paſſed through the ſkreen, may have time to ſlake thoroughly.

It appears to me that there is another reaſon, which the workmen do not notice, for their proceſs. Lime ſoon imbibes ſo much acidulous gas from the air, as to be increaſed in bulk, and in weight beyond the half of its former quantity; and as ſtucco for inſide work, for the ſake of a fine grain and even ſurface, muſt have a greater quantity of lime in its compoſition, than is neceſſary for cementing the grains of ſand together; the incruſtation would, by the acceſs of acidulous gas after it is laid on, be apt to ſwell and chip and loſe the even ſurface, if the lime were freſh when it is uſed in this exceſſive

exceſſive quantity. But this inconvenience is obviated by their proceſſes, in which the lime, whether ſlaked into water or otherwiſe, imbibes a conſiderable quantity of the gas, and is therefore the leſs apt to bliſter or ſwell, after the ſtucco is laid on.

THE builders conſidering the plaiſterers mortar or ſtucco as a finer and better kind of mortar, think it not amiſs to imitate them in thoſe particulars which are not attended with any expence, and eſpecially in the practice of ſlaking a great deal of lime at once, and of keeping the mortar made ſome time; and they do not ſeem to know, that ſuch meaſures prevent the mortar from ever acquiring that degree of hardneſs in which the perfection of mortar truly conſiſts.

SECTION

SECTION VII.

Of the Depravation of Mortar by the common Method of uſing the Water; and of the Uſe of Lime water.

FINDING by reaſon and experience, the advantage of totally expelling the gas, and preventing the return of it to lime or even to mortar before it is uſed; and knowing that common water, which is employed in great quantities, firſt in ſlaking lime, and then in making mortar, contains a great deal of the noxious gas; it occured to me that the vulgar proceſs of making mortar is in this freſh inſtance injudicious, as it tends to injure materials otherwiſe good.

THEY ſlake lime in ſuch a manner that almoſt the whole of the water is evaporated, and contributes nothing to the mortar, except ſo far as it depoſites its gas in the lime and injures it; and then the ſlaked dry lime and the ſand, require more water to make them into

into mortar. I have found the quantity of water uſed for both theſe purpoſes, to be twice the weight of the lime, at the leaſt.

THE quantities of acidulous gas known to be contained in the waters commonly uſed in making mortar, muſt greatly debaſe the lime which is thus expoſed to double its weight of ſuch water; and upon theſe grounds I was aſſured, *à priori*, that it would be a conſiderable improvement in mortar, to uſe no water in it except what has been previouſly freed from acidulous gas.

THIS is done in making lime-water; and the uſe of lime water appeared advantageous in another point of view. One ſeven hundredth part of lime water being lime, according to the experiments of Mr. Brandt which I find to be true; and this lime being introduced in a ſtate of ſolution which favours the cryſtalination of it between the grains of ſand, aſſiſts in cementing them together by the utmoſt attractive forces of its parts, if my notions of the polarity of theſe parts be true.

I MADE

I MADE divers experiments to try the practical validity of this reaſoning, and found it to be true; for on comparing ſpecimens of mortar made with my beſt lime ſlaked with river water, and ſand and water, and ſpread on tiles ſoaked in water, with other ſpecimens made with the ſame proportions of lime ſlaked with lime water and ſand and lime water, and ſpread on tiles previouſly ſoaked in lime water, the latter, at every age of them, were ſenſibly harder, and they adhered to the tiles better than the former. I muſt obſerve however, that ſuch diſtinctions cannot eaſily be made, except by thoſe who have a great deal of experience in theſe trials and compariſons. On repeated examinations of theſe and my other ſpecimens, I was highly encouraged in my purſuit; for thoſe made with lime water were better near the ſurface than any I had ever made; and I had good reaſons to be perſuaded that the extraordinary induration would proceed in time through the whole maſs.

SECTION

SECTION VIII.

Experiments made with a View to approximate the beſt Proportions of Lime Sand and Water, for Mortar.

IN reading over my notes, and examining the ſpecimens of mortar which I had hitherto made, I perceived that thoſe were the beſt which being made with common freſh lime, or with well burned lime, contained the leaſt of it; that is one ounce of lime in ſix or more of ſand; and finding this quantity of lime to be much leſs than is uſed in the common way of making mortar; and ſuſpecting that as a wall may be the weaker for its containing too much mortar, which widens the joints, ſo mortar may be weakened by the introduction of more lime than is neceſſary to cement the grains of ſand together; I thought another cauſe of the defect of common mortar opened to my view; and that it was adviſable to determine by experiment, what is the beſt

propor-

proportion of lime to ſand, in making mortar in which lime water is uſed.

I MADE five parcels of mortar with my beſt ſtone lime recently ſlaked with lime water, and with the coarſe Thames ſand, in the following proportions by weight.

1.

Slaked lime	—	—	1
Sand	—	—	4
Lime water, q. ſ.			

2.

Slaked lime	—	—	1
Sand	—	—	5
Lime water, q. ſ.			

3.

Slaked lime	—	—	1
Sand	—	—	6
Lime water, q. ſ.			

4.

Slaked lime	—	—	1
Sand	—	—	7
Lime water, q. ſ.			

5. Slaked

5.

Slaked lime	—	—	1
Sand	—	—	8
Lime water, q. ſ.			

THIS latter ſpecimen was not ſufficiently plaſtic for common uſe; or as the workmen expreſs themſelves, it was too ſhort. I further obſerved that the quantity of water required to make mortar to the proper temper, is greater as the quantity of lime is greater relatively to the quantity of ſand.

I SPREAD theſe on tiles in the month of June, and expoſed them to the air and the ſun, which then was very hot.

As my former experience taught me to expect that ſome of theſe, in haſty drying, would crack conſiderably; and as mortar, in building, is not liable to dry ſo quickly as theſe ſpecimens; in order to render the inferences from theſe experiments the more general, I made five other parcels of mortar in the ſame manner and expoſed them in the ſame way, in every reſpect, except that the direct rays of the ſun could not fall on them

or

or heat the pavement on which they ſtood. In three days I found this neceſſary, for the firſt of thoſe which ſtood expoſed to the ſun cracked conſiderably, the ſecond cracked leſs, the third ſhewed three or four very ſlender fiſſures viſible only on a very cloſe inſpection, the fourth and fifth ſhewed no cracks at this time, nor in a month afterwards, when the fiſſures of the others were conſiderably enlarged.

Of the ſpecimens kept in the ſhade and examined on the third day like the former, the firſt was cracked in divers parts, the ſecond ſhewed two or three very ſlender cracks, the reſt were not cracked in the leaſt, and never cracked afterwards, although I was forced to remove them to the place where the others ſtood.

Thus it appeared in a very ſhort time that an exceſs of lime diſpoſes mortar to crack, and conſequently injures it; that the higheſt proportion of lime to ſuch ſand, which may be uſed without incurring this inconvenience, depends on the circumſtances in which the mortar is to be expoſed; that no more than

one part of lime to ſeven of coarſe ſand ought to be uſed in mortar which is to dry quickly; and leſs lime may not be uſed, becauſe it does not render the maſs ſufficiently plaſtic for building or incruſtation; and that if a greater proportion of lime to ſuch ſand improves the mortar in any reſpect, it is to be uſed only where the mortar cannot dry ſo quickly as it did in the ſpecimens expoſed to the ſun.

In the courſe of nine months I clearly perceived that thoſe ſpecimens which ſtood in the ſhade for the firſt three days, were harder, and better in other reſpects, than thoſe which were ſuddenly expoſed to the ſun, the compariſon being made between the ſpecimens which contained the ſame proportions of lime, and which cracked the leaſt, or not at all: and of all the ſpecimens, thoſe were the beſt which contained one part of lime in ſeven of the ſand: for thoſe which contained leſs lime, and were too ſhort whilſt freſh, were more eaſily cut and broke, and were pervious to water; and thoſe which contained more lime, although they were cloſer in the grain, did not harden

ſo

ſo ſoon or to ſo great a degree, even when they eſcaped cracking by lying in the ſhade to dry ſlowly.

I THEREFORE concluded that haſty drying injures mortar made in any proportions of ſuch ſand and the beſt lime; and that the beſt proportion is one of lime in ſeven of ſand, whether the mortar is to be quickly dried or not.

I MUST obſerve however that theſe concluſions were made rather with a view to my future experiments, in which an approximation to the beſt proportions of lime and ſand and the beſt treatment of the mortar would ſave a great deal of trouble, than to any general and invariable rule for making mortar.

I RESERVED it to be mentioned in this place, that I ſet apart four ounces of each of the foregoing ſpecimens of mortar, and ſpread theſe portions ſeverally on plates of thin window glaſs, to the thickneſs of a quarter of an inch or thereabouts; and I noted the weight of each plate with its ſpecimen of mortar recently made.

These being equally expoſed to the ſun and weighed at different periods were found to loſe weight in equal times nearly in the proportion of the quantity of lime or of water uſed in making them; and the ſmalleſt loſs of weight when the ſpecimens were perfectly dry and conſiderably hardened, was one-tenth of the weight of the ſame ſpecimens recently made.

In many former experiments I had obſerved, but reſerved it to be mentioned in this place, that mortar which ſets without cracking, whether this be owing to the due proportion of ſand, or to the ſlow exhalation of the water from mortar containing leſs ſand; never cracks afterwards, whatever other faults it may have: the ſpecimens mentioned in this ſection, after a trial of eighteen months afforded the ſame obſervation.

By the ſetting of mortar, I underſtand that ſolidity which it acquires by mere drying, and which differs widely from the induration that takes place in time by other means which we ſhall preſently conſider.

Seeing

SEEING then that the quantity of water in mortar is as the quantity of lime, that the fiſſures happen only in the drying or ſetting, that the danger of cracking is greater, not merely as the quantity of water is greater relatively to the ſand, nor merely as the water is more expeditiouſly exhaled, but in a rate compounded of theſe; I inferred that mortar which is to be uſed where it muſt dry quickly, ought to be made as ſtiff as the purpoſe will admit, that is, with the ſmalleſt practicable quantity of water; and that mortar will not crack, although the lime be uſed in exceſſive quantity, provided it be made ſtiffer or to a thicker conſiſtence than mortar uſually is.

THIS inference was afterwards found to be true: for ſpecimens made thus with one part of lime and only ſix of the ſand, and others made with greater proportions of lime, but as ſtiff as they could be uſed, did not crack, in any expoſure: but they had faults which will be hereafter noticed.

SECTION IX.

Theory of the Induration dependent on the Proportions of Lime and Sand in Mortar, and Obſervations on the bad Effects of the vulgar Proportions of theſe.

IT is ſufficiently known that the aggregation of calcareous bodies, which burn to lime, or are chiefly compoſed of the matter of lime, is much weaker than that of the quartoſe; inſomuch that the ſteel which eaſily cuts all calcareous ſtones or ſpars, is as eaſily cut by the ſiliceous; and all ſtones, or powders which are choſen for cutting or grinding ſteel, are found to have this effect by reaſon of their ſiliceous or quartoſe particles.

THIS being conſidered together with divers obſervations heretofore related, I reaſoned in the ſubſequent manner.

As ſtones are cemented together in walls, by the mediation of mortar, ſo the grains of ſand

ſand or gravel are made to cohere and form a ſolid maſs of mortar, by the intervention of lime.

By the bare inſpection, as well as by the experienced induration, one part of lime paſte appears ſufficient to intercede the grains of ſeven of ſand without interruption of continuity, and in drying to fill the ſpaces between them, or to attract matter enough for this purpoſe from the air.

In this caſe the grains cohere at the ſmalleſt diſtances of them, and by means of the thinneſt laminæ of calcareous matter; and ſuch mortar is the ſtronger as it conſiſts of the greater quantity of hard quartoſe bodies cohering by means of the ſmalleſt practicable quantity of ſofter and brittle calcareous ſtrata; juſt in the ſame manner as a wall, built with porphyry and bad mortar, is, cæteris paribus, the ſtronger as the joints are made thinner: for all maſſes of ſuch ſtructure as mortar or cementious walls, reſiſt fracture and ruin, with powers of aggregation which are, not merely as the aggregation of the ſtones or bricks, nor barely as the aggregation of the ſofter cement, but in a ratio compounded of

theſe, and varying with circumſtances which we need not attend to at preſent; and thoſe maſſes therefore will reſiſt the moſt, in which the ſtronger aggregates bear the greateſt proportion to the weaker, ſo far as it is conſiſtent with the continuity of them.

SECONDLY, The ſmall ſtones which compoſe a heap of ſand do not imbibe water: their volume is not encreaſed by wetting them nor leſſened in drying; neither does a meaſure of wet ſand contract ſenſibly in drying: this laſt I have repeatedly experienced. But ſmall bits of lime are conſiderably increaſed in bulk by wetting them; and as the ſoft paſte of lime contracts greatly in drying, it muſt crack in every part where the drying paſte is prevented, by its adheſion to bodies or by other cauſes, from contracting uniformly and concentrically. As the contraction of mortar in drying, and its conſequent cracking, depend on the lime paſte, and not on the ſand, they muſt take place in the greater degree, as the quantity of lime and water is greater, and they muſt be leſſened or prevented by a due proportion of ſand; which proportion experience ſhews to be

be ſeven parts of ſand to one of lime. Thus we underſtand the cauſes of cracking, and how it happens that this defect is prevented by uſing leſs than the cuſtomary quantity of lime; and, although the lime ſhould be uſed in exceſs, by uſing leſs than the uſual quantity of water.

THIRDLY, The more perfect and expeditious ſetting and induration of mortar containing only one part of lime in ſeven of ſand, than of mortar made with greater proportions of lime, may be deduced from ſeveral concurrent cauſes. Having leſs water in its compoſition, it dries ſooner, and the calcarious matter cryſtalizing more quickly in it, gives it ſooner that ſolidity which we expreſs by the word ſetting. Having leſs lime in its compoſition, it is ſooner ſaturated with the matter which the air preſents, and which ſeems neceſſary to the induration of mortar; and in this ſaturation, the ſwelling of the lime is not ſo great as to puſh forth and derange the grains of ſand after they have once been placed and in ſome degree cemented together.

THIS

THIS latter inconvenience arising from the excess of lime, cannot easily happen in mortar compressed on all sides in massive buildings; but it manifestly occurs in the exterior parts of the joints in walls, where the mortar visibly swells and after swelling crumbles; it is likewise visible in the upper part of walls of modern construction, where the swelling is not prevented by a superincumbent weight. In these cases the joints become hollow; houses lately built look old or ruinous; and the bricks themselves, being bibulous, in such expoſure ſoften and moulder, in conſequence of the alternate wetting drying freezing and thawing; theſe being effectual agents in the diſſolution of all bodies which freely imbibe moiſture.

WITHOUT awaiting the event of thoſe experiments which I have lately made on the great ſcale, and ſhall point out before I conclude this eſſay, we may on theſe grounds alone aſſure ourſelves that the ſtrength and duration of the calcareous incruſtations compoſed of lime and ſand, will be greater, as we depart further from the proportions of lime and ſand commonly uſed, approaching to

to that of one part of lime to ſeven of ſand; becauſe the ſtucco which hardens the ſooneſt muſt be the leaſt injured, whilſt it is new, by the beating rains, and various accidental impreſſions; becauſe that which adheres moſt firmly to the other materials of buildings, and which acquires the greateſt degree of induration, muſt contribute moſt to the ſtrength of the walls, and beſt withſtand the ſhocks, attrition, and other trials to which the ſtucco is expoſed; becauſe that which contains the greateſt proportion of ſand, is leſs liable to be injured by any ſaline matter with which the air is ſometimes impregnated, as its calcareous matter is the better defended by the ſand: but above all, becauſe the ſtucco made with one part of lime and about ſeven of ſand, is not diſpoſed to crack: for incruſtations in this climate periſh ſooner by reaſon of the fiſſures than of any other defect; becauſe the water imbibed into the ſlendereſt of them, as well as into thoſe which appear on a curſory view, ſwells in the congelation, and dilates them; and frequent alternations of wetting and freezing, gradually widen them, until the ſtucco is bulged and torn from the walls.

SECTION

SECTION X.

Experiments on old Cements, authorizing the Proportion lately recommended of Lime and Sand.

TO diſcover the quantity of lime and ſand originally uſed in any hard and old cement which I find by a previous analyſis to conſiſt of lime and ſand or clean gravel, I break a pound of it into ſmall fragments, but not into powder, and with diluted marine acid I diſſolve and waſh away the calcareous part from the gravel or ſand. I meaſure the acidulous gas obtainable during the ſolution, and knowing the weight of any quantity of it in any temperature or weight of the aerial atmoſphere, I ſubtract this weight of acidulous gas and that of the ſand or gravel, from the whole weight of the mortar, and ſtate the reſiduary weight as that of the lime originally employed; knowing that it could not have made ſo hard a cement, if it had not been ſo far burned as to retain very little acidulous gas. I did not adopt this method of examination before I had found it to exhibit the

the lime and ſand of my oldeſt and hardeſt cements in the ſame proportions in which I had mixed them.

By this kind of analyſis, and by other trials, I found that the quantity of lime in old cements made with clean ſharp ſand, and noted for their hardneſs, was much leſs than is now commonly uſed in mortar; and that in the hardeſt, it was very near to that which my experiments indicate to be the beſt.

By ſharp ſand I mean that whoſe grains are bounded by flat ſurfaces.

Thus I found the inferences made from my compoſitions to be authenticated by long experience, ſo far as they relate to the proportions of lime and ſuch ſand.

SECTION

SECTION XI.

Experiments and Observations shewing the Agency of acidulous Gas in the Induration of Mortar, and Circumstances which impede or promote it. Practical Inferences.

THE observations made on divers specimens of mortar, at different periods, led me early into the opinion that the setting of mortar depends chiefly on the exsiccation of it, but that the induration is principally owing to the accession of acidulous gas in certain circumstances, and not to the drying, as the workmen generally imagine. In order to place this opinion beyond a doubt, and to discover the circumstances which favour or impede this induration, I made the subsequent inquiries.

EXPERIMENT I.

I MADE mortar with seven parts of the Thames sand, one of the best slaked chalk lime and the necessary quantity of lime water, and forming a part of it into oval pieces,

I put theſe into a gallon bottle, which I ſtopped cloſely with a ground glaſs ſtopple waxed; and I noted the groſs weight of the bottle and mortar, and placed it expoſed to the ſun. Having examined it frequently during the firſt month, I could perceive no alteration in the weight, nor any thing worth notice, except that ſome water exhaled out of the mortar, and condenſed in bright drops on the ſides and upper parts of the bottle. At divers times during ſix months afterwards I ſhook and weighed the bottle, and found the mortar quite ſoft and the weight of the whole unaltered.

Experiment 2.

Another portion of the ſame mortar was ſpread briſkly, as ſoon as it was made, on oblong pieces of dry and warm tile, and theſe were immediately placed over a ſand bath, where they were gradually heated to about an hundred of Farenheit for ſix hours, and then to an hundred and fifty for two hours more, when the mortar was dried thoroughly. I took particular notice of the ſolidity which it acquired in this haſty drying, and then put the pieces of tile with the adhering

hering mortar into a bottle closely stopped in the manner already described, marking the gross weight.

At the expiration of seven months, I found the whole unaltered in weight, and the mortar as easily cut or broken as it was when I put it into the bottle.

Experiment 3.

Another part of the same mortar was spread whilst fresh on a large tile, to the thickness of half an inch, and the tile was immediately placed in a tub, in which I put water to the depth of three inches over the mortar, and which I placed in the open air to receive the rain. At different times I broke the calcareous pellicle which formed on the water and defended it from the air, during the first fortnight: afterwards the wind and rain rendered this precaution unnecessary. In the course of six months, the mortar, instead of acquiring any solidity, was deprived of the greater part of its lime; and what remained on the tile, was not much different from a layer of wet sand.

Experi-

EXPERIMENT 4.

ANOTHER portion of the ſame freſh mortar was ſpread on a board ſtrewed with ſlaked lime to prevent adheſion, and placed in the open air, but ſheltered from the ſun. When this mortar became ſufficiently ſolid, which was on the ſecond day, I raiſed the pieces, which were about a quarter of an inch thick, from the board, and ſet them upright, fully expoſed to the weather, which was about this time dry and warm. In ſeven weeks after this expoſure they were indurated to a conſiderable degree. They reſiſted a cutting inſtrument nearly as much as Portland ſtone does, but not ſo well any force tending to break them acroſs at once. I then placed them under water as I had done by the former portion of this mortar.

After they had lain in the water four months I examined them attentively and found them, if at all altered, to be rather ſoftened than indurated further. I replaced them in the water, to be better ſatisfied about them; but by miſtake, they were removed in my abſence, and loſt.

EXPERIMENT 5.

SOON after the foregoing parcel of mortar was made, I prepared another in the ſame manner, and ſpread a part of it on a tile ſoaked in lime water, and placed the tile in the open air ſheltered from the ſun and rain. After it had ſtood a month in this ſituation, I placed it where it was ſheltered only from the rain.

EXPERIMENT 6.

ANOTHER portion of the ſame mortar was ſpread freſh on a warm dry tile, which I placed over a ſand bath, where the mortar was heated to about an hundred of Farenheit for ſix hours and then to an hundred and fifty for four hours more, at the expiration of which it was ſolid and perfectly dry. The next day I placed it in the open air, expoſed to the ſun, and the weather, which was dry and warm for a conſiderable time afterwards.

ON comparing theſe two laſt at the expiration of ſeven months, and again after ſix months more, I could eaſily perceive that the

the latter was inferior to the former; for it was much more eaſily cut and ſcaled from the tile and broken.

Experiment 7.

With mortar made, the day after I had made the former, of the ſame materials and in the ſame manner; and with new bricks, which I had heated almoſt to redneſs and ſuffered to cool to the temperature of my hands; I briſkly erected a little wall half a brick thick, on a ſtone bench raiſed for the purpoſe and fully expoſed to the weather.

Experiment 8.

On the ſame day and with the like mortar, and with cold new bricks previouſly ſoaked in lime water, I erected another wall, equal to the former in dimenſions, and placed in the ſame manner on a ſtone bench in the open air.

After nine months, in pulling theſe walls to pieces and in divers compariſons of the cement of them, I found that the latter cement adhered better to the bricks and was

harder than the former, inſomuch, that I had not a doubt about it.

EXPERIMENT 9.

IN a few days after I had made the experiment with the warm bricks, I conſidered the walls erected in variable weather, and the fence walls which are wetted frequently and deeply whilſt new, by rain, or by moiſture from the ground, and as often dried quickly; and I was deſirous to learn the effect of ſuch alterations of wetting and drying.

I. THEREFORE ſpread mortar, made like thoſe parcels lately mentioned, on a large tile ſoaked in lime water, and as often as it had dried, in fair weather, and generally at the interval of three days, I wetted it with rain water. In the courſe of nine months I found it was much leſs indurated than the ſpecimen made in the ſame manner, and defended from the rain: it moreover grew green by means of a vegetation which took place on the ſurface of it, and which thrived the more as the mortar was frequently wetted, or the tile longer ſuffered to lie flat on the ſtone bench already mentioned.

I HAD often obſerved ſuch a vegetation on mortar which I had made a few months before, eſpecially when, in the ſummer ſeaſon, I laid the tiles flat on the wooden border of a duſt-hole, or when, for want of room to preſerve the ſpecimens in, I piled many of them together in a damp corner on the pavement: I likewiſe ſaw that where the vegetation took place, the induration did not proceed as it does elſewhere: on the contrary, ſemi-indurated mortar ſoftened there.

ALL theſe being conſidered, I was ſatisfied that frequent wetting or conſtant moiſture, together with expoſure to air, injure mortar in a great degree, if it be not perfectly indurated by great age before it is expoſed to ſuch trials; and that the vegetation depends chiefly on moiſture.

EXPERIMENT 10.

BY the kind of analyſis mentioned in the tenth ſection, I repeatedly examined the proportion of acidulous gas to the lime, in the hardeſt of the old cements which I had collected; and finding it in the beſt of them to be, at the loweſt, in the proportion of three

to five, I rate the quantity of acidulous gas imbibed by good mortar, during the induration of it, at ſixty pounds at leaſt, for every hundred pounds of lime.

Experiment II.

Such mortar as that of the firſt experiment of this ſection was formed into ſlender pieces, each an inch broad, a quarter of an inch thick, and three inches in length. Theſe were placed in an airy paſſage, ſheltered from the ſun and rain, and were turned as ſoon as they could bear it without danger of cracking: they were then ſet upright and fully expoſed on all ſides to the air.

On the fourth day I ſlid four of the pieces, entire into a ſmall wide-necked glaſs retort, which I ſet deep in a ſand bath, with its nozzle immerſed in quickſilver, which ſtood cool whilſt the charge was gradually heated, in the courſe of forty-eight hours, to about ſeventy-five of Farenheit, which is under the temperature of incruſtations of this kind expoſed to the ſun in ſummer; and in the courſe of forty eight-hours more was ſlowly heated to about an hundred of Farenheit, to which

which degree incruſtations are frequently heated by the ſun in ſummer. As the retort cooled I admitted the neceſſary quantity of air, and then left it, with the nozzle immerſed deeply in the mercury, during three months. I then ſlid the pieces gently out of the retort, after having wiped away a few drops of water which adhered to the veſſel in their way; and immediately made the compariſon which I ſhall preſently mention.

Close to the retort, and in a ſituation where the heat was equal to that deſcribed, or nearly ſo, I placed four other of the pieces above deſcribed, on the fourth day after they were made: I encompaſſed them with the ſand, but ſecured a free acceſs and even a circulation of air to them. When the ſand bath was cooled, I put theſe pieces, which were thus perfectly dried, into a bottle which I ſtopped cloſely in the manner heretofore deſcribed.

On the ſeventh day after the pieces were made, on the twenty-firſt, and at the expiration of three months, I examined four pieces taken from different quarters of the

remaining parcel, and found the quantity of acidulous gas which they yielded, to correſpond with the degree of induration and the depth to which it had advanced in them reſpectively.

On comparing and examining the pieces dried in the retort and kept three months in it; the pieces dried in the ſame heat and freely expoſed to air during four days, but afterwards kept in a cloſe veſſel; and the pieces which dried and hardened in the free air, without being heated; I found that the firſt were friable in compariſon with the ſecond, and the laſt were by much the hardeſt and beſt.

As the ſecond tenth and eleventh experiments, together with obſervations formerly made, ſhew that the induration peculiar to mortar, is not cauſed by exſiccation; that it is greater, as the calcareous matter of cements approaches nearer to be ſaturated with acidulous gas; that it is retarded or prevented, as the acceſſion of acidulous gas is interrupted or obviated; we may conclude that this matter is a principal agent in the induration of calca-

calcareous cements and indiſpenſibly neceſſary to it.

By obſervations formerly made, but eſpecially by the compariſon of the fifth and eight experiments of this ſection with the ſixth and ſeventh, I learned that haſty drying prevents good mortar from ever acquiring the hardneſs which it otherwiſe would have; and that the more ſlowly the proper water of the mortar is exhaled or abſorbed from it, in incruſtations or brickwork, the more perfect will be the induration of it.

By the firſt third and ninth experiments of this ſection compared with the fourth, fifth and others, and by obſervations which led me to make theſe experiments; I diſcovered that mortar which is not ſuffered to dry, or which is ſupplied with moiſture as faſt as its proper water exhales, does not harden, or hardens only to a ſmall degree by any acceſſion of acidulous gas.

The fourth experiment indicates that mortar, whoſe lime has not yet imbibed its complement

plement of acidulous gas, although the maſs be conſiderably hardened, is liable to be injured by ſoaking in water, if it be pervious to water ſo freely as theſe thin pieces were.

ALL theſe experiments and obſervations conſpire to point out the circumſtances in which mortar becomes indurated the ſooneſt and in the higheſt degree, and operates moſt effectually as a cement. To this end it muſt be ſuffered to dry gently and ſet; the exſiccation muſt be effected by temperate air and not accelerated by the heat of the ſun or fire: It muſt not be wetted ſoon after it ſets; and afterwards it ought to be protected from wet as much as poſſible, until it is compleatly indurated: the entry of acidulous gas muſt be prevented as much as poſſible, until the mortar is finally placed and quieſcent: and then it muſt be as freely expoſed to the open air as the work will admit, in order to ſupply acidulous gas, and enable it ſooner to ſuſtain the trials to which mortar is expoſed in cementious buildings and incruſtations.

FROM theſe conſiderations we learn other cauſes, beſides thoſe already mentioned, of the ſpeedy ruin of our modern buildings.

THE

THE mortar made with bad lime and a great exceſs of it, and debaſed in watering and long expoſure, is uſed with dry bricks and not unfrequently with warm ones. Theſe immediately imbibe or diſſipate the water and not only induce the defect above noticed, but, as the cement approaches nearer to be dry, whilſt it is ſtill liable to be diſturbed by the percuſſions of the workmen, render it more nearly equivalent to a mixture of ſand and powdered chalk.

BUT to make ſtrong work, the bricks ought to be ſoaked in lime water, and freed from the duſt, which in common bricklaying, intercedes the brick and mortar in many parts. By this method the bricks would be rendered cloſer and harder; the cement, by ſetting ſlowly, would admit the motion which the bricks receive when the workman dreſſes them, without being impaired; and it would adhere and indurate more perfectly: the ſame advantages would attend the ſoaking of bibulous ſtones in lime water, and the uſe of grout; provided this were made with good lime ſand and lime water.

IN

In plaiſtering, the workmen always bruſh away the duſt and wet the wall on which they are to lay the cement, becauſe it will not otherwiſe adhere. From what has been already ſaid it is manifeſt that this ought to be done with lime water, and repeated as long as the wall is thirſty.

To perceive more clearly how much our ſlight buildings are weakened by the agitations and percuſſions to which they are expoſed, firſt in erecting the walls and ſettling the timbers, and then in driving thoſe wedges to which they faſten the wainſcots corniſhes and other ornaments, we muſt obſerve that the acceſſion of acidulous gas to mortar, was found to contribute nothing to the ſtrength of it, when it entered the compoſition before it was finally fixed in a quieſcent ſtate: and a little experience is ſufficient to teach us, that the ſame matter which aſſiſts in the induration of mortar, never ſerves to repair the fiſſures, or ſolution of continuity between the bricks and cement, which happen after it is ſet. When mortar is ſet, and before it is indurated, it may eaſily be ſerved from the bricks

bricks and crumbled; and for want of ſoftneſs it cannot bend into the fiſſures, or reſume its former condition in any time. Therefore by heavy blows, and in wedging, our walls muſt be greatly weakened; and the more, as the houſes are ſlight, quickly built, and haſtily finiſhed.

SECTION

SECTION XII.

Experiments ſhewing the beſt Kinds and Mixtures of Sand, and the beſt Method of uſing the Lime Water, in making Mortar.

PURSUING the analogy intimated in the ninth ſection, I thought that as large ſtones with carvilinear faces, bedded in common mortar, do not form ſo ſtrong a wall as they may when their interſtices are filled with fitting ſtones together with the due quantity of mortar; ſo mortar made with ſand, whoſe grains come near to be equal in ſize and globular, cannot be ſo ſtrong at any period of induration, as that which is made with the ſame mixed with as much fine ſand as can eaſily be received in its interſtices, in order that the lime may cement the grains by the greater number and extent of contiguous ſurfaces. By this notion I was excited to make proviſion for a new ſeries of experiments.

I CLEANSED a large quantity of the Thames ſand, by waſhing it in ſtreaming water, and ſorted

ſorted it into three parcels: the coarſeſt, which I call the rubble, conſiſted of ſmall pebbles, fragments of weathered ſhells, and grains of ſand of divers ſizes, which in waſhing had paſſed through a ſieve whoſe apertures were one eighth of an inch ſquare, but could not paſs through a braſs wired ſieve, whoſe meſhes were one ſixteenth of an inch ſquare, or rather larger: the next parcel, which I called fine ſand, conſiſted of grains of divers ſizes, which in waſhing paſſed through a finer ſieve whoſe meſhes were one thirty-ſecond of an inch ſquare: the third parcel conſiſted of grains the largeſt of which were waſhed through the coarſeſt ſieve, and the ſmalleſt were retained, in waſhing, on the fine ſieve: this I call coarſe ſand.

It is to be obſerved that the ſand which can paſs through a ſieve, in waſhing, is conſiderably finer than that which may be ſifted through the ſame ſieve, when it is dry.

Having dried theſe parcels on a ſand plate, and provided a narrow mouthed glaſs bottle capable of holding about two ounces troy of water, and a cylindrical glaſs veſſel which contained

tained twelve of these measures, I found by repeated trials, that the large vessel, charged to the brim with my rubble, might be made to hold somewhat more than one additional measure of it, when the rubble was well packed, by striking the bottom of the vessel frequently against the table perpendicularly. Charging the same vessel with coarse sand, I could by the same treatment make it hold two thirds of the thirteenth measure: and twelve measures of fine sand were so far contracted in this motion of the vessel, that it could hold one measure and one fourth more, or thirteen and one fourth in all.

After noting how far the interstitial spaces in each sized sand can be lessened by packing, I used water to shew what proportion these bear to the solids, in these different sands. I found that the thirteen measures of rubble which I stowed into the glass cylinder, could take in five measures of water, without any increase of bulk; or rather with a striking decrease of bulk: the twelve measures and two thirds of stowed coarse sand, imbibed four and one half of water, and yet decreased sensibly in bulk: the thirteen measures

measures and one fourth of fine sand packed, could drink in only four measures of water; but the diminution of bulk was more considerable than in either of the former; for the sand and water together measured less by one seventieth than the packed sand alone.

When sand was poured into the glass cylinder until it was filled, and water was added before the sand was packed, by a slight agitation of the vessel the sand contracted in a much greater degree than is above expressed. Upon the whole it seemed that water, by poising the grains, facilitates their sliding on each other to fit well and fill the spaces.

Until I had made these experiments I did not well understand, how the beating of new mortar makes it much wetter, and more plastic withal, than it can be made with the same proportions of water and solids, by mere mixture. I now perceive that beating produces this effect by closing the interstices of the sand, and rendering a small quantity of lime paste as effectual towards filling them and holding the grains together to form a

plaſtic maſs, as a greater quantity is, in ſand whoſe grains cannot fit each other ſo well.

Seeing that the interſticial ſpaces in ſand are ſo greatly leſſened by wetting it, I judged it expedient, for this reaſon alone, to expend all the water I ſhould henceforward uſe in making mortar, in wetting the ſand compleatly. I afterwards obſerved other advantages ariſing from this practice: for in filling the ſpaces with the fluid, the air is eaſily expelled, and the lime equably diffuſed in them by a little beating: but when the water is added to a mixture of lime powder and ſand, the air is entangled in the lime paſte, and cannot, without a great deal of beating, be totally preſſed out of the plaſtic maſs: I likewiſe found, that as an exceſs of water is injurious in mortar, this is an excellent method of regulating the quantity of water; for the portion of lime water which fills the ſpaces in ſand, and can be held by capillary attraction in a flat heap of it, is preciſely the quantity which makes well tempered mortar with one part of the beſt ſlaked lime and ſeven of the beſt ſand.

As

As I found ſome difficulty in expelling the air bubbles out of the ſand wetted in my deep cylindrical meaſure, even when I ſtirred up the maſs with a ſlender inſtrument, I concluded that the ſpaces in ſand are rather in a higher proportion to the ſolid ſubſtance of it, than they appeared in theſe trials: ſo that we may ſay they are at leaſt one third and more of any meaſure of the fine ſand, greater in coarſe ſand, and greateſt in the rubble. Suſpecting on another ground that theſe experiments did not ſhew the whole of the ſpaces in ſand, becauſe water tends to inſinuate itſelf between the contiguous faces of the grains, and conſequently to remove them aſunder, even whilſt it arranges them; I attempted to aſcertain the proportion of theſe ſpaces to the ſolids, by another method founded on this ſuppoſition, that the meaſured portion of ſand which weighs the moſt, has the ſmalleſt quantity of interſticial ſpace.

By the experiment, I found that a well packed meaſure of the rubble weighed twenty ounces three pennyweights; the like meaſure of the coarſe ſand packed, weighed twenty one ounces eighteen pennyweights:

and the ſame quantity, by meaſure, of the fine ſand, weighed twenty three ounces two pennyweights and twelve grains.

This trial correſponds ſufficiently with the former in ſhewing, that the ſum of the ſpaces in the rubble, is much greater than that of the coarſe ſand, and that the ſpaces in this are larger in the ſum, than thoſe of fine ſand.

In order to learn whether this proportion is maintained in all kinds of ſand, I tried by water and by weight in the foregoing manner, a great number of ſands uſed in London; ſuch as the coarſeſt glaſs-grinder's ſand, Hampſtead-ſand, Lynn-ſand, fine houſe-ſand &c.

The reſult of theſe experiments taught me that the ſpaces are always ſmaller as the ſand is finer, provided the compariſon be made between the ſorted fine part and the coarſeſt part of any kind of ſand: but this does not hold true in the compariſon of fine ſand and coarſe ſand of different diſtricts.

On examining the ſeveral ſpecimens of ſand with a lens, I perceived that, in ſome, the grains, however different in figure, were bounded by flat faces meeting each other in angles; whilſt in others, the faces were generally rounded, and the figure ſuch as the foregoing grains would be reduced to by grinding off their angles. The firſt kind I call ſharp ſand, the other round ſand. Then taking into conſideration the meaſurement already deſcribed, together with the ſharpneſs or roundneſs of the ſand, I found that the ſpaces are, in different kinds of ſand, as the ſize and roundneſs of them compounded; but they do not appear to be ſmaller in any kind of ſand that I have ſeen, than in our fine parcel of Thames ſand; which I think is owing to its being ſharper than any of the finer ſands which I had compared it with. The meaſure which contained twenty-three ounces two pennyweights twelve grains of the fine Thames ſand, contained only twenty-two ounces ten pennyweights of the Lynn ſand, which is a great deal finer, but rounder.

Having thus found the kind of ſand which, by reaſon of the ſize and figure of the

grains, has the ſmalleſt interſticial ſpace; I next endeavoured to aſcertain the mixture of coarſe and fine ſand, which leſſens this ſpace in the greateſt degree, which therefore requires the leſs lime to cement the grains together, and for the reaſons already mentioned, promiſes to make the hardeſt and moſt durable cement.

I found that nine meaſures of the ſhingle, and nine meaſures of the fine ſand, both well packed, meaſured when mixed and ſtowed cloſely ſixteen meaſures and one-eighth: that eighteen meaſures of the ſhingle and nine of the fine ſand tried in the ſame way, meaſured twenty-four: and that on mixing the ſhingle and fine ſand in various proportions, nine meaſures of ſhingle took, into its interſtices, one meaſure and one half of the fine ſand, without any increaſe of bulk.

I next learned that nine meaſures of the coarſe ſand and nine of the fine, meaſured in the like manner ſeventeen and a half: that eighteen ſuch meaſures of coarſe ſand well mixed with nine of the fine ſand, meaſured twenty-ſix: and that on mixing theſe ſands

in

in various proportions, eighteen measures of the coarse sand took into its interstices one measure of the fine sand, without any increase of bulk.

Lastly I found that eighteen such measures of the coarse sand and nine of Lynn sand, which is much finer grained than the foregoing, measured twenty-four when well mixed and stowed: and that on mixing them in various other proportions, nine measures of the coarse sand took into its interstices one and a half of the Lynn sand.

By these and a variety of similar experiments made on different sands, I found that the quantity of fine sand taken into the interstices of a coarse sand, was the greater without increase of bulk, as the grains of the coarse differed more from those of the fine in bulk, provided the drameters of the grains of coarse sand did not in general exceed those of the fine, in a proportion greater than five to one; that the greatest quantity of fine sand, which could be taken into the interstices of coarse sand, was one-sixth of the bulk of the coarse sand; and that in general the

mixture of ſix meaſures of coarſe ſand with one of the fineſt ſand, reduced the ſum of the interſticial ſpaces to nearly one half of the quantity of them in coarſe only, or in fine Thames ſand or rubble only.

Instructed by theſe obſervations I proceeded to the following experiments, in order to learn the advantages or defects attending each kind of ſand, and how far my expectations from the art of leſſening the ſpaces, were well founded.

I made ſeveral parcels of mortar with my chalk lime lime water and rubble in different proportions; the quantity of lime being in one a fourth of that of the rubble, in another only one-ſeventh, and in the others intermediate: I made other parcels of mortar with my chalk lime, lime water, and the coarſe ſand; and others with this lime, lime-water and the fine Thames ſand, in the laſt mentioned proportions.

I next made a great variety of ſpecimens of mortar; ſome of which conſiſted of rubble and coarſe ſand mixed in different proportions,

portions, wetted with lime-water, and blended with one-fourth or one-ſeventh or intermediate quantities of lime: others were compoſed of ſimilar mixtures of rubble and fine ſand with lime and lime water: and others conſiſted of rubble coarſe ſand and fine ſand mixed in different proportions, wetted with lime water, and beat up with the different quantities of lime lately mentioned.

I SPREAD a part of each of theſe ſpecimens of mortar, as ſoon as it was made, on a tile ſoaked in lime water, half an inch thick in ſome places, and much thinner in others: I placed the remainder of it, formed into oblong pieces of about an inch diameter, on the part of the tile which was not covered with mortar; and I ſet all the tiles numerically marked, in the ſituation formerly deſcribed, where they were equally expoſed to the weather: this was done in May, 1777: during the ſucceeding twelve months I examined each ſpecimen, and noted my obſervations, the moſt uſeful of which I ſhall endeavour to relate in a few words.

THE

The ſpecimens containing rubble and lime mixed in any proportion greater than five to one, were not fat enough, when freſh, to be conveniently uſed in building or ſtuccoing: but none of them, not excepting thoſe which contained the greater quantities of lime, cracked in drying. Thoſe which had the ſmaller quantities of lime in them, were very rough on the ſurface, coarſe in the grain, ſpongy, and eaſily broken: they ſhewed a defect of lime, becauſe thoſe which contained more lime were not ſo bad in theſe reſpects. By all of them it appeared that whenever ſuch rubble muſt be uſed, for want of ſand or finer gravel, the lime mixed with it muſt not be leſs than one-fifth of the quantity of rubble.

Of the ſpecimens conſiſting of coarſe ſand and lime, thoſe which had the ſmaller quantities of lime were too ſhort for common uſe, and could not be made to aſſume a cloſe and ſmooth ſurface, whilſt freſh; but in drying and hardening, they were in every reſpect preferable to the cements made with rubble and lime, in the ſame proportions: and of the ſame ſpecimens, thoſe were the beſt which contained

contained one part of lime in five of ſand; the others containing leſs lime being faulty like thoſe made with rubble, and thoſe in which the lime was mixed in much greater quantity, having the faults often obſerved to attend the exceſs of lime.

The ſpecimens which conſiſted of fine ſand and lime, were in general better than the foregoing: and that particularly which contained one of lime in ſix and an half of ſand, was in all reſpects much better than thoſe made with the ſame or any other quantities of rubble and lime, or coarſe ſand and lime. The ſpecimen which was formed with ſeven parts of fine ſand, and one of lime was not ſo compact and hard as that laſt mentioned. The compariſon of theſe two ſhewed that ſeven of ſand are too much for one part of lime, when the ſand is fine and unmixed with coarſe grains. The ſpecimen made with four parts of fine ſand, and one of lime had the noted faults attending the exceſs of lime; for it cracked in drying, and was ſenſibly injured in the winter, by thoſe alternations of drying, wetting, freezing, and thawing, formerly noticed.

On

On divers compariſons of thoſe portion of mortar made of fine ſand and lime, with the former, I was perſuaded that a better cement can be compoſed with ſuch ſand as I call fine, than with a coarſer ſand, whoſe grains are all larger than any of thoſe in my fine ſand; provided the coarſer ſand be not much ſharper than all that I have yet ſeen. If my experiments had been made in flow ſucceſſion, this laſt obſervation would have led me to imagine that mortar will be found the better as the ſand is finer.

Of the obſervations made on the parcels of mortar conſiſting of mixed ſands and lime, thoſe which follow are the moſt pertinent to our preſent enquiry.

The ſpecimens made with mixtures of rubble, coarſe ſand and different quantities of lime, reſembled thoſe made with rubble and lime in ſimilar proportions, when the rubble was predominant; and reſembled thoſe made with coarſe ſand and lime, in ſimilar proportions, when the coarſe ſand was predominant; and I could perceive

no

no advantage derived from the mixture of rubble and coarſe ſand; except that the cement was ſomewhat better as the quantity of rubble was leſs, relatively to the quantity of ſand and lime: but none of theſe ſpecimens were in any reſpect ſo good as thoſe made with fine ſand only.

Of the ſpecimens made with rubble and fine ſand, that was the beſt in which the fine ſand was twice the quantity of the rubble. But I could not perceive that any of theſe ſpecimens were preferable to thoſe made with the like quantities of fine ſand and lime; or that any conſiderable advantage is gained by the mixture of rubble and fine ſand.

Of the ſpecimens made of coarſe ſand fine ſand and lime, thoſe were manifeſtly the beſt, which conſiſted of four parts of coarſe ſand, three of fine, and one part or a little more of lime: for, whilſt freſh, they were more plaſtic than the others, and were eaſily made to aſſume a ſmooth ſurface; they were not diſpoſed to crack in this method of drying; they were not at all injured by wet or freezing or thawing; they were pretty cloſe in the grain; and they

they grew so hard, in the course of nine or ten months, as to resist the chizel, or any force tending to break the oblong pieces, much more powerfully than any of the specimens lately mentioned. I noted them as the best specimens of mortar that I had ever made; and one part of lime, in four of coarse, and three of fine sand, to be a better proportion than any other of the sands and lime, for incrustations.

Of the various specimens of mortar made with mixtures of the rubble, coarse sand and fine sand, those were the best, in which the fine sand was equal or nearly equal in quantity to the rubble and coarse sand; in which the rubble was not much more than one seventh part of the quantity of both sands; and in which the weight of the lime was one seventh of the weight of the sand and rubble, or a little more: But these specimens, when fresh, were less plastic, and less capable of assuming a smooth surface under the trowel, as the quantity of rubble was greater; and I could not find they were preferable in any particular to those respectively which were made with similar quantities of lime and the mixtures of coarse and fine sand lately commended.

Upon the ſtricteſt compariſon, I concluded, that one part of rubble in three of coarſe and three of fine ſand, makes as good mortar with lime, as can be made with the ſand and lime without rubble, for any purpoſe which does not require a finer cement; but there is no advantage gained by the uſe of rubble where the coarſe and fine ſand can be had equally cheap, unleſs a rough ſurface be required.

In ſtuccoing walls the rubble promiſed to be uſeful in pointing and in the firſt coat; becauſe a roughneſs of this coat makes the finer exterior coat adhere more firmly.

In the review of all theſe ſpecimens it appeared, that the quantity of lime, which forms a maſs ſomewhat plaſtic with ſand and water, is the ſmalleſt quantity neceſſary for making the beſt mortar which ſuch ſand can afford; and that any further quantity of lime is uſeleſs in the coarſer ſands, and injurious in the finer: that the neceſſary plaſticity is induced by the ſmaller quantities of lime, as the interſtices of the ſand are ſmaller in the ſum, and as the grains fit each other the better in conſequence of the due mixture of coarſe and fine

fine ſands: but that the leſſening of the interſticial ſpaces, by the mixture of fine ſand with the coarſe, does not enable us to leſſen the quantity of lime ſo far as might be expected in conſequence of our notions of the ſpaces meaſured by water. It ſeems that the grains of fine ſand are held aſunder by the lime paſte, to a greater diſtance than they are by water; and that the reaſon, why the finer ſand requires more lime than the coarſer and mixed ſand, is, that the ſpaces, which are more numerous in fine ſand than in the coarſe, are more augmented in the whole quantity of them, by the particles of lime, which intercede alike the coarſe and the fine grains.

SECTION

SECTION XIII.

Experiments ſhewing the Effects of fineſt Sand and quartoſe Powder, in Mortar: Obſervations on the fineſt calcareous cements: Practical Precepts.

THE laſt mentioned notion led me to ſuſpect, ſoon after the foregoing experiments were made, that, although the fine Thames ſand made better mortar than the coarſe ſand or the rubble afforded, the mortar will not always be the better as the ſand is finer, however ſharp it be. I therefore procured a large quantity of the very fine pit-ſand uſed in London under the name of houſe-ſand: I waſhed away the clay with which it abounds, and dried it: viewing it, when thus cleanſed, with a lens, I eſtimated the ſize of the grains to be, at the medium of the largeſt and ſmalleſt, about one ninth part of that of my fine Thames ſand: this I call fineſt ſand. At the ſame time I was favoured, by my neighbour Mr. Bentley the ingenious manufacturer of the ornamental Staffordſhire ware, with the

neceſſary quantity of the fine powder of calcined flints, which is prepared for his manufactory.

WITH divers mixtures of theſe with lime water and lime, in a variety of proportions; and with each and both of theſe, blended with coarſe and fine ſand, lime and lime water in ſimilar proportions; I made a great number of ſpecimens of mortar, which I tried in the manner already deſcribed; and noting my obſervations on them, I found the following to be the moſt eligible for the conciſe recital intended in this eſſay.

MORTAR containing the quantity of lime neceſſary to the plaſticity and other deſireable properties of it, or a greater quantity of lime, is the more liable to crack in drying, as the ſand of it is finer.

MORTAR made with this fineſt ſand and lime, does not grow ſo hard, or reſiſt fracture ſo forcibly, as that made with my fine Thames ſand and lime, in the ſame proportions, or any others neareſt to theſe. But the former mortar, when compoſed of about ſix parts

parts of ſand, one of lime, and the neceſſary quantity of lime water, and ſlowly dried, becomes much harder than any of the common calcareous ſtuccos, uſed by plaiſterers.

MORTAR compoſed of lime, my fine Thames ſand, and the fineſt ſand, is the worſe as the quantity of fineſt ſand is greater: and this holds true in every tried proportion of the ſands and lime.

MORTAR conſiſting of lime, coarſe Thames ſand, fine Thames ſand, and fineſt ſand, is the worſe as the quantity of this laſt is the greater, when the compariſon is made between it and the cement made with the ſame quantities of lime and the beſt mixture of coarſe and fine Thames ſand.

MORTAR made with flint-powder, lime and lime water, in any proportion, is more liable to crack in drying, than mortar compoſed of any ſand and lime: it is moreover incapable of hardening to ſo great a degree; whether the hardneſs be tried with a chizel, or by breaking it acroſs. But mortar made with about five parts of flint-powder, one of

lime, and the neceſſary quantity of lime water, is nevertheleſs preferable to any ſtucco now uſed in inſide work, for the finiſhing coat; becauſe it has a more lively whiteneſs, and aſſumes a finer ſurface, which I think might be made to imitate that of marble: It requires however to be dried very ſlowly.

MORTAR made with coarſe Thames ſand, fine Thames ſand, flint-powder and lime; or with fine Thames ſand, fineſt ſand, flint-powder and lime; or with the fineſt ſand, flint-powder and lime; is the worſe, as the quantity of flint-powder is greater, relatively to that of the ſand.

UPON the whole it appeared, that the fineſt ſand is injurious in mortar which is expoſed to the weather, and that flint-powder is ſtill worſe: but that this laſt may be advantageouſly uſed in compoſing ſtucco for inſide work, in which, a fine texture, pleaſing colour, and ſmooth ſurface, are preferred before extreme hardneſs; and in which the drying may be regulated ſo as to prevent the incruſtation from cracking.

INSTEAD

Instead of reſting ſatisfied with the bare diſcovery of the fact, that very fine ſand, or quartoſe powder, is incapable of making ſo good a cement as may be formed with coarſer ſand, although fine Thames ſand and lime make a better cement than can be compoſed with the coarſe ſand and lime; and that the mixture of very fine ſand, or ſiliceous powder, with the Thames ſand, is rather injurious than uſeful, although the mixture of the fine with the coarſe Thames ſand, is better for mortar, than either of them unmixed; I took a great deal of pains to learn the cauſe of this, in order to confirm or correct the foregoing notions, and render the precepts which flow from this fact, the more ſatisfactory.

By ſorting my fineſt ſand into divers parcels, in ſifting it through different ſieves; by meaſuring the meſhes of theſe; and by viewing the grains of each parcel ranked cloſely on a ſcale; I perceived, more clearly than I had done before, the roundneſs of this ſand: I moreover found that the grains of the coarſeſt parcel were, at a medium of their reſpective bulks, upwards of ſixteen

times larger than thoſe of the fineſt parcel, the grains of the other parcels being of divers intermediate ſizes. As this ſand therefore has every advantage attainable by the mixture of coarſe and fine grains, and every diſadvantage reſulting from the ſmallneſs and roundneſs of its grains, I learned the reaſon why the defects attending ſuch fine round ſand in mortar, are not corrected by any mixture of coarſe ſand. How theſe defects are induced by the fineſt ſand and flint-powder, we may conceive in the following manner.

HAVING already ſhewn how the roundneſs of ſand tends to render the mortar made with it defective, I may, without any further illuſtration of this matter, reckon on this figure of the grains of fineſt ſand, as one cauſe of the imperfection of the mortar in which it is uſed.

THERE is nothing to prevent the laminæ of lime paſte, which intercede the grains of fineſt ſand, from being as thick, in the maſs of mortar made with it, as they are in mortar made with coarſer ſand; but they are likely to be thicker in general, as the faces of the finer

finer grains are rounder: The number and extent, moreover, of theſe laminæ, muſt be greater, in the ſum, in the fineſt ſand than in the coarſer: and it is for theſe reaſons, that more lime paſte is required to make mortar with the former than with the latter; ſince the mortar is not formed, until the paſte envelopes every grain, and fills the interſtices. In this view of the ſubject, we diſcover another cauſe of the defect lately mentioned. If we uſe lime with a ſparing hand, it will not extend between all the grains or fill the ſpaces; we find the mortar too ſhort whilſt freſh; and it is as defective in ſtrength, when indurated, as it is deficient of the cementing matter. When we uſe the neceſſary quantity of lime, the calcareous matter bears a greater proportion to the quartoſe grains, in this fineſt mortar, than in the coarſer; and this renders the former defective, according to the principles of aggregation already expreſſed.

A THIRD cauſe of the imperfection of mortar, made with fineſt ſand, or containing a large quantity of it, appears, on the conſideration of the quantity of lime. We have repeatedly ſeen that mortar contracts the more

in drying, and is the more apt to crack, as it contains a greater quantity of lime paſte: and as the fineſt ſand requires an extraordinary quantity of the paſte to form it into mortar, the aggregation of ſuch a cement is likely to be impaired by fiſſures, although they do not always appear, by reaſon of their ſmallneſs.

OTHER cauſes, of the experienced imperfection of fine mortar, might be added, which have no relation to the figure of the grains of ſand or the quantity of calcareous matter; but to avoid an exceſs of theory, I forbear to mention them, and ſhall only add a conjecture concerning the finer cements.

WHEN a cementious maſs, like mortar, is cut with an edged inſtrument, or broken acroſs, we may obſerve that the fracture happens in the ſhorteſt line, along the laminæ of the weaker cementing matter, and ſeldom or never in the ſhorter right line paſſing thro' the harder grains and the cement alternately, although the impreſſed force tend to cauſe the ſolution of continuity in the ſhorteſt, or in a right line. By the principles of mechanics, the

the reſiſtance to ſuch forces is greater, *cæteris paribus*, as the line of fracture is longer, whether it be ſtraight, or winding in any courſe: and it it for this reaſon, that a wall built with very large ſquare ſtones, is leſs liable to crack, although the foundation ſhould fail near one extremity of it, than a brick wall built with the ſame kind of cement on the like ground; or that a wall, whoſe bricks are jointed in the preſent faſhion, is more ſecure from cracking, than that which ſhould be built, on the like infirm ground, with the ſame kind of mortar and bricks ſtanding over each other, not jointed, but with their ſides and ends fluſhed, as the workmen expreſs it.

As cements are cut and broken in the direction of the cement, and not in the ſhorter line; as the cracks in ill-founded walls run winding along the joints, inſtead of going in the ſhorteſt courſe through the bricks and joints alternately; and as the reſiſtance of ſuch cementious maſſes, eſtimated by mechanical theory, is greater, as the line of fracture is neceſſarily elongated by the ſtronger aggregation of certain parts of them; I am inclined to think that calcareous cements made with lime

lime and quartoſe matter, will always be found weaker, under the trial by the chizel or by fracture, as the quartoſe ſand or powder is finer; becauſe the line of fracture, which takes the courſe of the cementing matter, is ſhorter, in any equal depth of ſuch maſſes, as the hard quartoſe grains are finer and rounder.

As flint-powder conſiſts of exceedingly fine grains of ſilicious ſtone worn to roundneſs in the grinding, what has been ſaid of the fineſt ſand is ſufficient to ſhew, why the cements, which contain flint-powder, are the worſt of all thoſe we have mentioned.

The cuſtomary method of waſhing ſand, even for ſtucco which is to be expoſed to the weather, conſiſts in paſſing it through a ſieve, by a circular horizontal motion of it, in a tub filled with water, which flows over, and carries away with it any light matter which can be long ſuſpended in water, as faſt as the ſand runs through the ſieve into the veſſel. But this proceſs is inadequate to our views; becauſe the fineſt ſand ſubſides along with the beſt, and theſe, in the precipitation

cipitation, entangle and carry down with them a great deal of finer powder or dirt. Where ſuch a method muſt be purſued, for want of other utenſils, or through the ſcarcity of water, the ſand ought to be agitated again in ſmall parcels, with a part of the water which has cleared by ſubſidence; and immediately after the agitation, the muddy water ought to be poured off, before the light parts have time to ſubſide in it. But the uſeful part of the ſand is more effectually freed from the finer and noxious parts, by ſifting it in ſtreaming water, whoſe current is to be ſo managed, that it ſhall carry away the mud and the ſand which is too fine, whilſt the better part ſubſides in a proper receptacle. This art may be gathered from the practice of the Corniſh miners, in waſhing their pounded ores, better than from any written precepts.

In the ſubſequent pages I propoſe to ſhew the integrant parts of gravel, and their ſeveral properties in mortar: for my preſent purpoſe it will be ſufficient to obſerve, that the gravel commonly employed in building conſiſts chiefly, after it is ſkreened, of rubble, coarſe

coarſe ſand, fine ſand, and fineſt ſand, ſimilar to thoſe uſed in our experiments. This is obvious on the bare inſpection of it, and leads us to diſcover another cauſe of the weakneſs of our modern cements, in the compoſition of which, no other precaution is uſed, reſpecting the gravel, except to ſeparate the ſtones and coarſeſt rubble from it, by ſkreening.

When it happens that the ſkreened gravel contains more than a certain quantity of rubble, relatively to that of coarſe and fine ſand ſimilar to thoſe deſcribed, the mortar made with it muſt, according to our experiments, be defective. It will be ſo likewiſe, whenever the coarſe ſand of it predominates over the fine ſand, to a greater degree than that which was found conſiſtent with the perfection of mortar: and when the quantity of fineſt ſand happens to be conſiderable in gravel, the mortar made with it muſt be faulty in a greater degree. Now ſuppoſing the gravel to be freed, by the ſkreening, from every thing more injurious than fineſt ſand and quartoſe powder, we perceive that the artiſt, who is ignorant of the advantages of

ſizing

ſizing his gravel, and uſes it in its native ſtate, as chance preſents it, has the odds greatly againſt his making good mortar, although he may ſometimes do it, without knowing the reaſon, as we ſhall find hereafter: for his chance is, that the native gravel ſhall conſiſt of coarſe and fine ſand mixed in the proportion of 4 to 3, or of the rubble, coarſe and fine ſand mixed in the proportions above recommended; and that it ſhall contain little or no ſand like our fineſt ſand: but the chances againſt him are as numerous as there are other diſtant proportions of rubble coarſe and fine ſand in gravel, and as the kinds of gravel uſed are, which contain the fineſt ſand or ſtill finer quartoſe grains, in efficient quantity.

In great cities, where gravel cannot be procured ſo cheap as the rubbiſh of old walls, which the workmen lay in the ſtreets to be ground to powder by the paſſing carriages, they uſe this rubbiſh ſkreened, in the place of ſand or gravel, in making mortar. It conſiſts of the groſs powder of bricks, and of mortar indurated, as much as bad mortar can be, by time; and ſome builders affirm that it is better

better than ſand or gravel, for mortar. It is certainly eligible when the price is chiefly conſidered; in any other view, it is not ſo. From my paſt experience I judged the calcareous powder of an old cement, and that of the bricks, to be a brittle periſhable and weak ſubſtitute for grains of ſand; and the quantity of duſt in ſuch ground rubbiſh, to be highly injurious: but as the opinion of the workmen was againſt me, I made ſome trials of it.

I FOUND that leſs lime was requried to make fat mortar with this ground rubbiſh, than with my beſt mixtures of ſand; which is no ſmall recommendation of it in certain jobbs, and is owing, in my opinion,, to the ground calcareous part, which, ſo far as it is finely powdered, is equivalent to whiting: but the mortar made with the rubbiſh appeared, in every ſtage of induration, and in every compariſon except that of the plaſticity, to be greatly inferior to that made with mixed ſand and lime, in the ſame proportions.

IF the workmen would confine their opinion to the compariſon of ſuch rubbiſh-mortar

tar, with that in which clayey gravel is uſed, or with the cements made with the aſhes and ordure of the town, dug out in preparing foundations of houſes, in thoſe places which were formerly receptacles of ſuch matter, they might maintain it on divers grounds which will be examined hereafter; but otherwiſe it is erroneous.

SECTION

SECTION XIV.

Experiments made on a larger Scale with our beſt Mixture of Sands Lime Water and Lime.

IN the ſpring and ſummer of the year 1778, I repeated a great number of the foregoing experiments, particularly thoſe which exhibit mortar in the improved ſtate to which I had brought it; and finding my former obſervations to be true, when the circumſtances were not varied, I reſolved to try my beſt cements in larger quantity and in other circumſtances. I applied them in the way of ſtucco, on the brick walls of houſes, in different aſpects, but chiefly in that of the meridian ſun; covering a ſquare yard at leaſt with each ſpecimen, after I had repeatedly wetted the wall with lime water.

By theſe trials I found that mortar, made with four parts of coarſe ſand and three of fine wetted with lime water and beaten up with one of my lime ſlaked with lime water, although

though it could be eaſily ſpread on a horizontal plane, or uſed in building with bricks, was rather too ſhort for plaiſtering on the perpendicular ſurface of a wall. It might however be laid on, in ſmall ſucceſſive portions, by a dexterous management of the trowel, and eſpecially by ſliding the inſtrument on it upwards.

When the weather continued temperate and dry for eight or ten days after the incruſtation was made, and no great quantity of rain fell for three or four weeks afterwards, this ſtucco anſwered my expectations; for it did not crack in the leaſt, and in three months was almoſt as hard as Portland ſtone, at the ſurface, where the induration firſt takes place for the reaſons formerly mentioned; but it was too coarſe to repreſent a fine grained ſtone.

Having made two pieces of incruſtation of this kind, on the ſame wall, and knowing that calcareous cements cannot harden ſo ſoon as it is neceſſary in outſide ſtuccoing, unleſs they be pervious to acidulous gas, in which caſe they may drink in water likewiſe, I

frequently wetted one of the pieces, in about three months after it was formed, with lime water, expecting that the calcareous matter of it would cryſtallize in the cement and render it cloſer and harder. I was not diſappointed; for in the courſe of a month I found this piece of ſtucco harder and cloſer than the former, and at the ſurface, as much ſuperior in theſe particulars, to Portland ſtone, as the other was inferior to it. I have ſince found that lime water has not this effect, if the incruſtation be wetted with it, before it is quite dry and indurated ſlowly, to vie with Portland ſtone in that kind of ſtrength which is tried by grinding Portland ſtone on it, or ſcraping it with a chizel; for any other trial of incruſtations is unfair, until the induration has proceeded equally through the whole maſs.

When the incruſtations made of the ſame cement, were wetted by rain, in two or three days, or ſooner after they were applied, and eſpecially when the wind blew the rain forcibly upon them, they were ſenſibly injured, for they never afterwards looked or hardened ſo well as the former ſpecimens of ſtucco.

In

In theſe particulars the large incruſtations agreed with thoſe made on tiles. But the ſame agreement did not appear in the incruſtations which I had made with the ſame compoſition, on a wall which fronted the meridian ſun, at a time when the weather was very hot; for theſe ſhewed a few ſlender cracks in the courſe of three days. When in the ſame ſituation and weather, and on a coarſe ſtucco of this kind, I ſpread, in about two hours after it was laid on, a thinner coat of cement made with finer ſand, in order to repreſent a finer grained ſtone, the incruſtation conſiſting of theſe two layers, cracked more than the former.

After many repetitions of theſe experiments, in the hotteſt weather, with the ſame event, I perceived that the trials of ſuch cement on tiles, are not ſo ſevere as thoſe to which they may be expoſed ſometimes in incruſtations on walls. In this latter caſe, the ſtucco is very unequal in thickneſs; for in the hollow joints and depreſſions of the bricks, it is near an inch thick, when over the prominences it has not more than one-eighth of this thickneſs; and as it dries ſooneſt in the thin parts,

the unequal contraction ſeems to be the cauſe of thoſe cracks, which would not happen to the ſame cement laid on the flat ſurface of a tile: it ſeems moreover that ſuch a compoſition may more eaſily contract in drying, without cracking, as the cruſt is made narrower or leſs extenſive. But I impute the cracking chiefly to the foregoing unequal contraction accelerated not only by the heat of the ſun and the wall, but by the thirſty bricks; for if we form our judgment according to the quicker or ſlower progreſs of the exſiccation, and the ſtiffneſs which the cement acquires in the act of ſpreading it on the brick wall, the wetting of this laſt ſuperficially with lime water, is not equivalent to ſteeping the tiles for a few minutes in the ſame liquor.

When, with the view of preventing fiſſures, I ſtuccoed a part of the ſame wall wetted with lime-water with cement containing the mixed ſands and lime in the proportion of fifteen to two, in the ſame kind of weather, I found the difficulty and waſte, in applying it, greater than in the former inſtances, and that it was defective in ſtrength and cloſeneſs, for want of lime, although it did

did not crack. When, through diſtruſt of my former experiments, I uſed more than one-ſeventh of lime, the cracks were ſtill larger and more numerous.

To guard a recent incruſtation from the rain, and to ſecure it from cracking in the circumſtances laſt deſcribed, I propoſed the expedient of hanging ſail cloth on the cornices and ſcaffolding; but the expence of this meaſure, and the danger of it in windy weather, were ſtrong objections.

EMBARRASSED by this unexpected difficulty, I reſolved to change my ground, and try what might be done by a new ſeries of experiments, in which I intended to uſe every known cheap ſubſtance, whether it could be reaſonably ſuppoſed to have any conſiderable effect towards ſecuring a recent incruſtation againſt the above-mentioned impreſſions of rain or hot weather, or could be ſuſpected of rendering the ſtucco defective. I proſecuted this enquiry with great alacrity, becauſe I was certain that, although I ſhould fail in the attempt towards improvement, I ſhould learn how in future to avoid thoſe

things, which being natively blended in certain kinds of lime ſtone ſand or water, tend to render the mortar made with them faulty. I had already conceived a notion, which I ſhall ſubmit to my reader before I conclude, concerning the excellence of ſome antient cements; but leſt I ſhould be miſled by it, I proceeded, in all the experiments which I am to relate, on the ſuppoſition that this excellence is owing to ſome matter, accidentally introduced in the materials which the Antients found in the diſtricts contiguous to their moſt durable cementious works, or deſignedly blended with their mortar.

SECTION

SECTION XV.

Experiments ſhewing the integrant Parts of Gravel, the Choice and Preparation of it; and the Effects of Clay, Fuller's Earth, and Terras, in Mortar.

ON inſpecting different kinds of gravel uſed in London and in divers parts of England, in making mortar, I obſerved that they all contained ſome clay; and that this was generally coloured with martial matter. In conſideration of the frequency of this matter in mortar, I made it the firſt ſubject of my preſent enquiry.

By the art already deſcribed, I ſorted three buſhels of ſkreened gravel dug up near Portland Place in Marybone pariſh, into five parcels; one equivalent to our rubble, another to coarſe ſand, another to our fine Thames ſand, another to our fineſt ſand; and the remainder was ſet apart as clay or bolar earth. I dried all theſe, and reduced the lumps of clay to an impalpable powder,

HAVING treated divers other ſpecimens of gravel in the ſame manner, I found that gravel, freed from the larger pebbles by ſkreening, may generally be conſidered as a native mixture of rubble, ſands, and clay; and that when the clay is waſhed out, the reſiduary parts of the different kinds of gravel, differ in ſize, ſharpneſs, colour and hardneſs; thoſe being the hardeſt which conſiſt chiefly of quartoſe matter. Judging of gravel according to the precepts derived from my trials of ſand, I rank that dug in Marybone amongſt the better kinds of gravel, and uſed no other in mortar.

AFTER a great number of trials of cements made with my beſt chalk-lime, lime-water and the gravel, or certain parts of the gravel, and applied on tiles and on a wall, I found that thoſe made with the coarſe and fine ſand of the gravel, ſeparated from the reſt of it, and mixed in their native proportions, were the beſt; that thoſe made with the rubble coarſe ſand and fine ſand mixed in their original proportions, but containing no other part of the gravel, were the next in hardneſs and the other deſireable qualities; that

that thoſe containing all the parts of the gravel except the clay, in their native proportions, differed in nothing, that I could diſcover, from theſe laſt, for the fineſt ſand of this gravel was not a fiftieth part of the maſs of it; that thoſe containing the rubble ſands and clay in the ſame proportions, and thoſe made with the unwaſhed gravel, appeared on a cloſe examination to be the worſt of all theſe: and thoſe containing the native unwaſhed gravel mixed with twice its proper quantity of the clay of ſuch gravel, ſhewed moſt clearly that clay is highly injurious, by diſpoſing the mortar to crack in drying, to ſoften in wet weather, and to moulder when the quantity of clay is one-eighth of that of the ſand; but in much ſmaller quantities, it only prevents the cement from acquiring the hardneſs peculiar to good mortar, and conſequently diſpoſes it to periſh in a few years.

WITH my beſt mixtures of Thames ſands lime water and lime, I blended fine fat tobacco-pipe clay, in different proportions, and expoſing theſe ſpecimens, I perceived that the effect of clay is greater as it is purer and fatter.

ter. The ſpecimens in which the quantity of fat clay was one-ſeventh or one-eighth of that of the ſands, mouldered early in the winter like marle.

THESE appearances were not altogether unexpected: for in experiments formerly made with a view to the improvement of fire-veſſels, I had obſerved that clay adheres but weakly to any hard bodies, however ſlowly it is dried on them, and that maſſes compoſed of clay and ſand in divers proportions, never acquired any conſiderable hardneſs by the mere drying and expoſure to air: It was therefore not likely that clay ſhould add to the ſtrength of mortar: but as dried clay greedily imbibes water and ſwells with it, and in drying contracts greatly and cracks, if any thing prevent it from contracting equably; and as marle ſtones, which conſiſt of clay and calcareous earth, moulder in the weather; it was to be expected that clay would be hurtful.

THESE experiments point out another cauſe of the defects of the common mortar, and ſhew that the gravel or pit-ſand to be uſed in any

any valuable building, ought to be freed from the clay by waſhing, which will be found a very cheap operation, even in cities, if the water which carries off the clay, be directed into a place where it may be depurated by ſubſidence, for repeated uſe: they likewiſe direct us in the examination and choice of theſe, and ſhew that the viler kinds may be made equivalent to our beſt mixture of Thames ſand, or nearly ſo, by waſhing and ſorting, and then rejecting the exceſs of rubble or fine ſand.

I MUST obſerve however that ſome kinds of gravel cannot be made fit for mortar by this proceſs: for the grains of them, which reſemble thoſe of rubble and coarſe ſand, conſiſt of ſmaller grains cemented by clay, which is ſo far indurated that it cannot diffuſe itſelf in the water ſpeedily.

FULLERS EARTH tried in the ſame manner was found to operate in the mortar like clay, in every reſpect, as I might have preſumed, except that the former was leſs injurious than the clay, when the quantities of them were equal.

TERRAS,

TERRAS, which is a volcanic production conſiſting chiefly of clay and calx of iron indurated together, when it was ground to an impalpable powder, produced the effects of fuller's earth, in mortar, the more ſenſibly as it approached nearer to be one-ſeventh of the quantity of ſand. The coarſer powder of terras had leſs effect.

A MORTAR made of terras powder and lime was uſed in water fences by the Romans, and has been generally employed in ſuch ſtructures ever ſince their time. It is preferred before any other, for this uſe, becauſe it ſets quickly, and then is impenetrable to water: whence ſome people haſtily conclude that it is the beſt kind of mortar for any purpoſe. But by experience I know that mortar made of lime and terras powder, whether coarſe or fine, will not grow ſo hard as mortar made with lime and ſand, nor endure the weather ſo well; but on the contrary is apt to crack and periſh quickly in the open air. The efficacy of it in water fences is experienced only where it is always kept wet, and ſeems to depend on the property which the powder of terras has, in common with other in-

indurated argillacious bodies, and eſpecially the boles, but in a higher degree, of expediting the cryſtallization of the calcareous matter, by imbibing the water in which it is diffuſed in the mortar, and of ſwelling, during this abſorption, ſo much, as to render the cement impenetrable to any more water: it ſeems alſo that an acid of the vitriolic kind, which is contained in terras as well as in boles, contributes to the ſpeedy ſetting of this cement, by reducing a part of the lime to the condition of gypſum.

SECTION

SECTION XVI.

Experiments ſhewing the Effects of Plaiſter Powder, Alum, Vitriolic Acid, of ſome metallic and earthy Salts, and of Alkalies, in Mortar. Practical Inferences.

IN my beſt mixtures of coarſe and fine Thames ſand with one-ſeventh and with larger quantities of lime, I tried the gypſeous powder of which plaiſter of Paris is made; and found it to be injurious in proportion to the quantity of it. The particular effects of gypſum in mortar, were ſuch as might be expected in conſequence of our knowledge of the ſaline nature of it; gypſum being a compound of calcareous earth and vitriolic acid, which is ſoluble in water, not ſo freely as neutral ſalts, but rather like lime: it diſpoſed the mortar to ſet faſter than it could be applied in ſtuccoing; it contributed very little to the plaſticity of it; and the cement was the more apt to ſoften in wet weather and to periſh in time, as the quantity of plaiſter powder

der in it was greater. The greateſt quantity tried was only one-ſeventh of that of the ſand.

ALUM was found very injurious. The acid of alum formed ſelenite or gypſum with a part of the lime, and thus operated like gypſum or plaiſter powder; whilſt the earth of the alum induced the imperfections which attend the uſe of clay. The greateſt quantity of alum uſed was one part in ten of the beſt mixture of ſand and lime; and this ſpecimen mouldered, in nine or ten months, like marle.

VITRIOLIC acid, which formed ſelenite or gypſum with a part of the lime, produced the effects of a quadruple quantity of plaiſter powder.

VITRIOLS of lead and of tin, being decompoſed by the lime, operated like ſmaller quantities of vitriolic acid: martial vitriol or copperas had the ſame effect, and induced an olive colour, which was ſoon turned to that of ruſt.

VITRIOL

VITRIOL of zinc or white vitriol, and Epſom ſalt, did not diſpoſe the mortar to ſet haſtily, nor injure it in any particular diſcoverable during the application and drying of it; for theſe vitriols are not eaſily decompoſed by lime: but afterwards I perceived that they impeded the induration of the ſtucco, and diſpoſed it to ſuffer by the weather, the more as the quantity of either of them came near to be one-tenth of the quantity of ſand.

VITRIOLATED tartar, Glaubers ſalt, and the ſalts which are found in moſt of our waters, ſuch as ſea ſalt, nitre, marine calcareous ſalt, calcareous nitre, and that compoſed of magneſia and marine acid, were found like Epſom ſalt to injure the beſt mortar: ſo were cauſtic mineral alkali; cauſtic vegetable alkali; and liquor ſilicum. Cauſtic volatile alkali, which ſoon exhales by reaſon of its volatility, had no ſenſible effect. I did not try argol or mild alkalies, becauſe they reduce the lime to whiting; neither did I uſe any acid which forms a very ſoluble ſalt with lime, for obvious reaſons.

KNOWING

KNOWING that the lime which has been employed by ſoap-boilers to render their barilla and pot-aſh cauſtic, contains, even after the repeated elixations, a little alkali and vitriolated tartar blended with the calcareous earth; and that the greater part of this laſt is reſtored to the condition of chalk, by the acidulous gas imbibed from the alkaline ſalts; I had, in conſequence of the foregoing experiments, ſufficient reaſon to preſume that this refuſe matter of the ſoap-boilers cannot anſwer the purpoſes of lime, or improve our mortar. But as a pretence to the contrary is made by ſome artiſts, and appears in the Builder's Dictionary, and as the cheapneſs of this article is a temptation towards their extending the uſe of it, I reſolved to decide this queſtion by direct experiment.

AFTER trying, in my uſual method, ſpecimens of mortar made with the refuſe of ſoap-lees and my beſt ſand, in different proportions; and others made with this ſand, lime, and the refuſe matter, in various proportions; I found the firſt deſtitute of the moſt uſeful properties of good mortar; and the others were defective, in proportion to the

quantity of the refuſe matter relatively to that of the lime. Whether this matter improves mortar made with gravel and the common chalk-lime, or encreaſes the defects of it, is a queſtion not worth our notice.

The experiments lately related ſhew that lime is the more unfit for building and external incruſtations, as it contains more gypſum; and I muſt now remark that moſt kinds of lime-ſtone uſed in England contain conſiderable quantities of this matter which is not much corrected in the burning: But as I have, in the ſecond ſection, enabled my readers to diſcover this imperfection, I hope I ſhall be excuſed from the invidious office of depreciating or recommending any particular lime-ſtone or manufactory of lime.

The cautions which our laſt mentioned experiments ſuggeſt with regard to the uſe of water, are eſpecially neceſſary in this country, where moſt of the wells and ſprings abound with one or more of the above-mentioned ſalts; and it is not to be preſumed that the quantity of theſe contained in water which is uſed for culinary purpoſes, cannot be

be injurious in mortar; for I know that ſelenite, Epſom-ſalt, the very deliqueſcent ſalts compound of magneſia and marine acid and of calcareous earth and the ſame acid, may, together with a little ſea-ſalt, be natively diſſolved in water, to the quantity of half an ounce in a gallon, without affecting the taſte of it ſenſibly. When we conſider the quantity of water neceſſary in ſlaking the lime making the mortar and wetting the thirſty bricks, and the ſmallneſs of thoſe portions of ſalts, whoſe injurious effects were diſcoverable in the courſe of one year, or in a ſhorter time, we find ſufficient grounds for concluding that ſuch ſaline waters will be found hurtful in mortar, before many years elapſe, particularly where it is expoſed to moiſture. Indeed this has been already experienced of ſea-ſalt, even in the ſmall quantity of it introduced in mortar, when the ſand is taken from the ſea ſhore. The eaſieſt method of diſcovering the quantity of ſaline matter in water, conſiſts in evaporating it ſlowly to dryneſs and weighing the reſidue: water which depoſites calcareous earth as ſoon as it is heated, ought to be cleared by ſubſidence or filtering, before the evaporation is compleated.

When a choice can be made, rain water is to be preferred; river water holds the next place, land water the next, ſpring water the laſt; and waters noted medicinally or otherwiſe for their ſaline contents, ought not to be uſed at all in mortar; for the ſalts contained in them are thoſe which were tried, the vitriolated tartar excepted.

SECTION

SECTION XVII.

Experiments ſhewing the Effects of ſkimmed Milk, Serum of Ox-Blood, Decoction of Lint-ſeed, Mucilage of Lintſeed, Olive Oil, Lintſeed Oil, and Reſin, in Mortar; and the Effect of painting calcareous Incruſtations.

AT the ſame time and in the ſame mixtures of the beſt ſand and lime, I tried ſkimmed milk, ſerum of ox-blood, decoction of lintſeed ſtrained, and thick mucilage of lintſeed, in the place of lime water.

THE mortar made with any of theſe was fatter as the liquor was more glutinous, but was as liable to crack as mortar made with water. In the courſe of a year it appeared that each of theſe liquors encourages a vegetation to take place on the ſurface, which gives it an ugly appearance, and tends to ruin it; and that they all prevent the cement from acquiring the experienced hardneſs of

our beſt compoſitions, or indeed from having any competition with them in this particular.

THE notion therefore which is entertained by the builders, concerning the uſe of ſkimmed milk and blood, is erroneous, unleſs it be confined to the viler kinds of mortar, which may perhaps be improved by them; becauſe a compoſition of ſand whiting and mucilage, grows harder than that of whiting and ſand kneaded with water.

IT ſeems to me that glutinous liquors and good lime act reciprocally on each other, in the time of mixing them, to the deſtruction of their reſpective characters, and particularly to the converſion of a part of the quick lime into whiting; and that if any kind of mortar is improved by them, it is then eſpecially, when the workman takes advantage of the fatneſs induced by them, and uſing leſs than his cuſtomary quantity of lime, ſecures his work from cracking.

OLIVE oil mixed with good mortar, or ſubſtituted in the place of a part of the lime water,

ter, rendered the cement defective, as the quantity of oil was greater. The greateſt quantity uſed was half that of the lime.

Lintseed oil uſed in the ſame manner, makes the mortar fatter, retards the drying of it, and prevents it from acquiring in any time, ſo great a degree of hardneſs as it otherwiſe would have. It was the more hurtful as the quantity of it was nearer to that of half the lime: in much ſmaller quantities it was leſs injurious than olive oil. From my obſervations on this ſubject, and on the compoſitions called oil cements, I have reaſon to conclude, that no oil ought to be uſed in a cement which conſiſts chiefly of ſand lime and water; nor any water or watery liquor, in a cementious mixture, which is moiſtened and kneaded with oil chiefly.

As lintſeed oil whiting and ſand make a cement which hardens to a great degree, in dry ſituations, and abides the weather a long time before the hardened oil relents, it is not improbable that lintſeed oil may meliorate mortar made with bad lime. But good lime and lintſeed oil ſeem to injure each other, in form-

ing a kind of ſaponaceous compound with the lime water of the mortar.

From the experienced effects of ſaline, gelatinous, and oleaginous matter, I infer that cow-dung, which I have not tried, would impair good mortar. It makes the common mortar fatter, and in that reſpect more convenient for pargeting the interior ſurface of chimney flues: it ſeems likewiſe to prevent the parget made with bad lime, from drying ſo quickly and from cracking ſo much as it otherwiſe would do; the fibrous part of the dung being capable of contributing largely to this latter effect. On theſe grounds it may be uſeful in bad mortar thus applied, whether it increaſes the hardneſs of it or not; altho' it is likely to impair good mortar.

Powder of reſin intimately blended with mortar by grinding it with a part of the lime and lime water, was hurtful according to the quantity of it; the greateſt quantity tried being one-fourth of that of the lime.

Before I knew the event of theſe experiments I made an incruſtation on a wall fronting

ing the ſouth, but ſhaded from the ſun after mid-day, with a cement compoſed of ſeven parts of my mixed ſand, one of the beſt ſtone lime, and the neceſſary quantity of lime water. As ſoon as the incruſtation was dry, which happened in four days, I painted one-third of it with lintſeed oil prepared for painters uſe, another third with white lead paint, and the remainder was ſeparated from theſe by a channel cut between them.

After fourteen months the laſt-mentioned portion was very hard near the ſurface, and the induration extended deeply in the maſs of it, though not in ſo great a degree of perfection as that of the ſurface: The painted portions were alſo very hard at the ſurface, but internally much weaker than the other.

From my obſervations of theſe ſpecimens, and of divers incruſtations in this city, which being made of bad calcareous cement, have been painted and ſanded, in order to fill the cracks and fence them from the weather; I have had ſufficient reaſon to conclude, that an incruſtation, made as good as it may be with lime and ſand and lime water, is not bettered by painting

ing it as ſoon as it dries; that this covering retards the induration of it, by cutting off its communication with the air; that it therefore renders it liable to be irreparably injured in wet weather, wherever the water can get behind the paint; and that if paint or oil ought ever to be applied on ſuch ſtucco, it ought not to be uſed in leſs than a year after the incruſtation is made: I likewiſe found that the painting and ſanding of the common defective incruſtations, contributes very little to their duration, although it hardens them at the ſurface; for it does not effectually prevent them from cracking; and it avails very little to paint the cracked ſtucco again; becauſe cracked ſtucco is always hollow, as the workmen term it; that is, it parts from the wall in the parts contiguous to the cracks, ſounds hollow on being ſtruck with the knuckle, and falls off in a few years, if it be ſo thick and large in extent as to break the adhering portions by its weight.

SECTION

SECTION XVIII.

Experiments ſhewing the Effect of Sulphur, introduced by different Methods, in Mortar.

IN my firſt trials of ſulphur, it ſeemed to be uſeful; and this led me to try it in ſo many different ways, and in ſo many mixtures of lime and ſands, and of theſe with flint powder and divers other ſubſtances, as would render the recital of all my obſervations on the effects of it inconſiſtent with the plan of this eſſay: I muſt therefore content myſelf with communicating thoſe which I think moſt uſeful, in ſuch terms as may give ſome intimation of the manner in which the experiments were made.

WHEN the livigated powder of ſulphur was mixed with mortar already made of good materials and did not exceed one-thirty-ſecond part of the maſs, it ſeemed to improve it, in the firſt and ſecond month, and ſometimes during a longer time of compariſon with mortar

mortar made of all the ſame materials, except ſulphur, in ſimilar proportions: But in ten or twelve months the ſulphur was found injurious, and the more ſo, as it exceeded the foregoing proportion. The moſt hurtful effect of it was, its diſpoſing the mortar to relent in long continued rains, and grow quite friable after a few alternations of freezing and thawing. It had the ſame effect in mortar containing ſeveral of the ingredients already named and of thoſe hereafter to be mentioned.

When the ſulphur was mixed with freſh powdered lime, and theſe were ground briſkly with lime water, a calcareous liver of ſulphur was formed, proportionate to the quantity of ſulphur uſed; and the mortar made with this mixture and ſand, or with this and ſand and other ingredients, was worſe than mortar containing an equal quantity of the ſulphur mixed in it in the former method.

The tranſparent liquor called liquid calcareous liver of ſulphur, which conſiſts of ſulphur diſſolved in water by the intervention of lime, being uſed inſtead of water in making mortar with ſand and lime in any proportions, was found more injurious

jurious than three times this quantity of undiſſolved ſulphur was, in the firſt-mentioned method of uſing it: and this liquor had the like effect in mixtures of mortar with divers other ingredients. Whence I infer that ſulphureous mineral waters ought not to be uſed in mortar.

If the plan of theſe experiments had not comprehended the noxious as well as the uſeful ingredients, and I had not reſolved to diſtruſt every theory, I might have prognoſticated the event of theſe mixtures, in conſequence of my certain knowledge of the operation of ſulphur lime and air on each other.

When ſulphur and lime are moiſtened with water, and expoſed to air, the acid of ſulphur being attracted by the lime, whilſt the phlogiſton of the ſulphur is attracted by the air, a decompoſition of the ſulphur takes place, and new compounds are formed. The acid and lime gradually form ſelenite or gypſum, whilſt the air combined with the phlogiſton is wafted away. Therefore lime, by ſo much of it as is thus expended in forming gypſum,

gypſum, is not only unable to act as a durable cement of the grains of ſand, but is capable, according to the experiments of the ſixteenth ſection, of counteracting the cementing powers of the reſiduary part of it, when the maſs of ſulphurated cement is expoſed to the weather.

THE pleaſing warm colour which ſulphur induces in calcareous ſtucco, whilſt it is freſh, and the promiſing appearances of ſuch an incruſtation in the firſt year, have, if I am rightly informed, already miſled an artiſt to apply it freely at his own riſque. I wiſh theſe obſervations may ſerve to undeceive him.

ABOUT this time, the imitation of coloured ſtones, by incruſtations, became an object of my attention; and ſome of the ſubſequent experiments were made with a view to it, as well as to the purpoſes already expreſſed.

SECTION

SECTION XIX.

Experiments ſhewing the Effects of Crude Antimony, Regulus of Antimony, Lead Matt, Potter's Ore, White Lead, Arſenic, Orpiment, Martial Pyrites and ſlaked Mundic, in Mortar.

CRUDE antimony reduced to an impalpable powder and then ground with the lime and lime water, operated in mortar as ſulphur does when it is uſed in the ſame manner and in the quantity which the crude antimony contains. The antimonial powder moreover induced a diſagreeable blueiſh colour, which in a little time became brown and afterwards yellowiſh.

WHEN the powder of antimony was mixed in the mortar after it was made it was leſs injurious.

REGULUS of antimony tried in the ſame way, ſeemed to have no other effect than that

that which is produced by the admixture of flint powder or other fine powders of hard bodies.

POWDERED lead matt and potter's ore of lead acted like crude antimony, but more slowly and weakly in equal quantities of them.

WHITE lead was found exceedingly injurious, which I expected; for I had long before discovered and shewn in my public Courses of Chymistry, that a great part of white lead is acidulous gas, into which vinegar is easily convertible in the process for making white lead and in many others; and I foresaw that the lime, attracting this matter, would be reduced to the condition of whiting in the time of making the mixture, and that the mortar would consequently be defective. The white lead, as fast as its acidulous gas is drawn from it by the lime, becomes yellow like massicot. As white lead improves the oil cements, these experiments shew that there is no true analogy between the calcareous water cements and those which are called oil cements.

ARSENIC

Arsenic operated in mortar like the neutral ſalts; and orpiment produced the injurious effects experienced of ſulphur and of arſenic; which effects were greateſt when the orpiment was ground with the unſlaked lime and lime water. Orpiment imparted a dark brown colour at firſt, which ſoon became yellow and afterwards diſappeared.

The martial pyrites called mundic, heated to redneſs, and then ſlaked by moiſtening it with water whilſt it was hot, operated like crude antimony, with this difference only, that a greater quantity of it was required to produce the ſame effect; for this reaſon, as I conceive it, that the quantity of ſulphur in martial pyrites is leſs than in crude antimony, and being held in it by a more forcible attraction, is prevented from acting ſo freely on the lime of the mortar. The colour induced by the ſlaked mundic was at firſt blueiſh and afterwards turned to that of iron ruſt.

The mundic, which was that of Wiel-Virgin in Cornwall, uſed in its native ſtate, in mortar, kept me in ſuſpence upwards of twelve months. It was tried not only on

tiles, but in large incruſtations on walls, becauſe it promiſed great advantages at firſt. When the quantity of it did not exceed one twenty-fourth of that of the mortar, it manifeſtly increaſed the induration of the cement during the firſt nine months; but after fourteen or fifteen months it diſpoſed the incruſtation to relent, the more as it was oftener wetted or as the place was damp, and from being exceedingly hard, to become penetrable to a pointed inſtrument puſhed only with the hand, and as brittle as chalkſtone. The colour and changes of colour of the mortar containing native mundic, are ſimilar to thoſe produced by the ſlaked mundic, and are not at all pleaſing to the eye. The effects of much ſmaller quantities of this matter in mortar do not yet appear ſo clearly; but there is no reaſon to preſume that they will be of the ſame kind, though in a ſmaller degree.

THESE and the preceding experiments indicate that all bodies ſoluble in water, not excepting arſenic, and all thoſe which are capable of efflorеſcing, or of being decompoſed by air and moiſture, are hurtful in mortar; and they teach us to avoid thoſe kinds of gravel which

which are impregnated with pyritous matter, whether it be arſenical, metallic, aluminous, or calcareous. The effects of regulus of antimony, and the ſpeedy decay of the cheaper metals, however perfectly they are deſulphurated, give ſtrong grounds for preſuming that calcareous cements, which are to be expoſed fully to the weather, are more likely to be injured than improved by metallic matter introduced in any form.

SECTION XX.

Experiments ſhewing the Effects of Iron Scales, waſhed Colcothar, native Red Ochres, Yellow Ochres, Umber, Powder of coloured Fluor, coloured Mica, Smalt, and other coloured Bodies, in Mortar. Advices concerning coloured Incruſtations, Inſide-Stucco, and damp Walls.

IRON ſcales from a ſmith's forge, which conſiſt of iron ſemi-calcined, and are thought by many artiſts to improve mortar, were tried eighteen months ago, by grinding them to a fine powder, and mixing this in mortar, to half the quantity of the lime, and in ſmaller proportions.

THE larger quantities, in the courſe of twelve or fourteen months, appeared to be hurtful; and by theſe I judge of the ſmalleſt, which do not yet appear to produce any remarkable effect in incruſtations made in dry ſituations, except the ruſty colour which they induce. But in thoſe which reached near

near the ground, and in others made on tiles which were laid flat on the ground in a ſhaded damp corner, in both of which inſtances the incruſtations were always moiſt, the iron powder ſeemed to render the cement a little harder than it could otherwiſe become in the ſame time in ſuch circumſtances, and it certainly made it cloſer in the grain.

By theſe experiments I am inclined to think that iron powder, which, during its converſion to ruſt, imbibes a great deal of acidulous gas and air, and ſwells conſiderably, may be uſed with ſucceſs, where the proper induration of good mortar is prevented by continual moiſture, and the chief purpoſe of the cement is, to exclude water perfectly, by the cloſeneſs of its texture, to which the ſwelling of the iron contributes not a little. If it is capable of producing any deſireable effects in cements otherwiſe circumſtanced, theſe are to be expected only when the quantity of it does not exceed one-eighth of that of the lime, or one-fiftieth of that of the maſs of mortar.

WASHED colcothar of iron, native red ochres, yellow ochres, and umber, had the effects of ſmaller quantities of terras, or of equal quantities of flint-powder.

COLOURED fluor and micaceous ſtones, coloured marble, ſmalt, and divers other coloured ſubſtances, which are inſoluble in water, reduced to fine powder, induced their reſpective tints in the incruſtations, but acted like flint powder.

FROM the experienced effects of coloured calces of iron, and of divers ſulphurated and periſhable metallic powders, I learned that theſe ought not to be uſed in external incruſtations; ſince they render them more defective as they colour them deeply; and I turned my thoughts to the diſcovery of ſome other expedient for inducing permanent colour without injuring the cement.

I SOON found that this may be done, with regard to the lighter and pleaſanter tints, by the uſe of coloured ſands, or the coarſe gritty ſorted powder of hard and durable coloured bodies. Lynn ſand affords a white cement which

which is the better, as more of the fineſt part is ſifted out of the ſand. Thames ſand makes a grey cement not unlike Portland ſtone, and this colour is agreeably varied by the uſe of grey bone-aſh, of which we ſhall preſently treat.

A RICH yellow tint is obtained by uſing the golden yellow ſands, of which kind there is one near Croydon in Surrey; and a ſmall quantity of this ſand mixed with Lynn ſand, gives a warm white, and with Thames ſand, an exact reſemblance of the Bath ſtone. Theſe are the moſt eligible tints for the fronts of houſes.

UNTIL I had tried the gliſtening ſcaly talcs, I imagined they would ſerve to impart all other tints, as they may be had of any colour, and are as durable as they are pleaſing to the eye: but they were found to weaken the adheſion of the cement to the wall, and to make it ſo rough and ſhort, that it was almoſt impoſſible to form a ſmooth compact incruſtation with it, unleſs the lime were uſed in exceſſive quantity; and in the courſe of eight or nine months it ap-

peared that the cements, in which they were mixed in the quantity neceſſary to produce ſtrong tints, were rendered ſpongy, and greatly weakened by them.

Scaly gliſtening mica, ſtrewed equably on an incruſtation previouſly wetted with a thin mixture of lime water and lime, and gently compreſſed to lay the ſcales flat, imparts its colour with the fulleſt effect. In this way coloured mica may be uſed, where it is cheap, on external incruſtations, if the perſpective appearance of a building can be improved by different colours of any members of it: and this kind of colouring greatly excels painting, in the fickle weather of our climate, becauſe it laſts unfaded, as long as the micaceous cruſt.

To tinge a cement ſufficiently for proſpect or contraſt, of any colour which is not found in ſand, ſo that the incruſtation ſhall not be impaired, and that the colour ſhall be as durable as the cement; I found nothing more adviſeable than to uſe, in the place of the ſand, or of a part of it, coloured glaſſes or coloured ſtones of the hardeſt kind, beaten to coarſe

coarſe powder, the finer parts of which are to be waſhed away, not merely becauſe they are injurious to the cement, but becauſe I have obſerved that they contribute very little to the intended colour.

THE drying, induration, and texture of incruſtations made on brick walls and other irregular ſurfaces, are always ſo far unequal as to exhibit viſible traces, which deform the work and cannot be effectually obliterated by any known method ſo convenient as that of covering the firſt coarſe incruſtation, after it has dried, with another coat which may be made finer and ſmoother. Thus the expence of fine grained ſmooth or coloured ſtucco is rendered moderate; becauſe the finer, or the colouring materials, may be reſerved for the exterior coat, which will laſt for ages, if the cement be good; as we ſhall ſhew, when we come to conſider the experienced duration of the beſt calcareous cements.

As the mouldings and paintings which are expended on the ſoft ſtucco now uſed, and which contribute ſo much to the magnificence of our apartments, can be equalled, in their

their ornamental effects, by the double incruſtations which I have deſcribed, and greatly exceeded by theſe laſt in the hardneſs and duration of them, I do not doubt that plaiſterers will adopt this improved method, when they find that it is conſiſtent with their own intereſt, as well as with that of their employers.

I AM not ſufficiently acquainted with their buſineſs to form a juſt eſtimate of this ſubject; but I will ſubmit to their conſideration a few obſervations which would influence me very much in the choice of ſtucco for a houſe of mine.

THE compoſitions heretofore uſed for ſtuccoing within doors, are incapable of hardening conſiderably, and when they are laid on the naked walls, ſoon become tarniſhed, unſightly, and inconvenient, by the damps which the workmen call ſweating, and which are, in my opinion, of two kinds; one I will call damp by tranſpiration, the other damp by condenſation. The damp by tranſpiration occurs, when the principal walls are ſtuccoed before they have dried, or when the

the materials of them are ſo ſpongy as to imbibe the rain, and the circulation of air within the houſe is not ſufficient to waft away the moiſture which tranſudes from the wet wall into the ſtucco; and eſpecially when the exhalation of this moiſture from the ſtucco, is impeded by the cloſeneſs of its texture; for all ſuch bodies retain moiſture the more forcibly, as their pores are ſmaller, and as the air meets more difficulty in pervading them. I ſee no reaſon to doubt that this inconvenience would be obviated by making the incruſtation of a texture ſimilar to that of the materials on which it is laid; and that the cement made with about ſeven parts of ſand, one of lime, and the lime water, and improved, as we ſhall teach hereafter, by the admixture of bone-aſh, would continue dry in ſuch circumſtances, becauſe moiſture quickly exhales from it, by reaſon of its texture.

The damp which ſeizes incruſtations, when the walls are badly conſtructed, when the joints of the facing bricks become hollow by the decay of the mortar, or when the copings

pings or gutters are defective, do not fall under our conſideration.

THE damp by condenſation appears moſt on the fineſt and cloſeſt incruſtations, however perfect and old the walls may be. To find the proximate cauſe of it, we need only to advert to that which gathers on glaſs windows, whilſt the wainſcoat and other ſpongy bodies, which ſerve to incloſe the ſame rooms, remain dry; or to the moiſture which gathers on walls faced with the cloſer kinds of ornamental marble, in ſumptuous buildings, at the ſame time when the walls and incruſtations, which are contiguous to them, and are of a coarſe texture, are quite dry. In theſe and other inſtances we may perceive, that the damp is owing to the cloſeneſs of theſe bodies, and that a ſtucco pervious in a certain degree to air and moiſture, will be free from it, as well as from the other lately mentioned.

THE plaiſterers, finding their ſtucco, which is as fine and cloſe as they can make it, liable to contract theſe damps, eſpecially on the principal walls of houſes, caſe them with lath-work, on which the incruſtation is laid diſtant from the wall. In this way they

they obviate the appearance of damp; but they at the ſame time contract the rooms, and narrow paſſages and ſtaircaſes ſenſibly, at a great expence. This is enhanced by the repeated plaiſtering neceſſary to fill the ſlender cracks which disfigure their incruſtation during the drying, and by the oiling or painting which is finally required to hide this defect compleatly, if not to give colour. Thus the work becomes coſtly, although the plaiſterers profit is moderate.

On theſe conſiderations I am inclined to the opinion that it will be found as advantageous to the plaiſterer, as to his employer, to prefer our cement before any other, for internal incruſtations; eſpecially when no other colour is required, beſides thoſe which may be imparted by coloured ſand, or materials which do not greatly exceed it in price. I would not interfere with the workman, in forming an exact comparative eſtimate of the expences, if I could do it; but I will venture to affirm that an incruſtation made as I have deſcribed, or in the improved method hereafter to be ſhewn, will be found ultimately cheaper than any other yet diſcovered, for the

the following reaſons. It will be more durable by reaſon of its greater hardneſs; it will retain its colour longer unfaded, becauſe the colouring materials do not tarniſh or periſh like paint; it will preſerve the ſharpneſs of the mouldings and the elegance of its appearance longer, becauſe it will not require the frequent painting which ſoon blunts the figures and mouldings of ordinary ſtucco; it may be finiſhed with leſs labour, becauſe it is not apt to crack in theſe circumſtances, and does not need many coats and repeated plaiſtering; and as it is not likely to contract damp, it will ſave all the expences and inconveniences of lath-work, whether it be laid on partitions or on principal walls, provided the cement applied on the former be not made of the fineſt materials.

If a poliſhed and white ſurface of our ſtucco ſhould be required, it ought to conſiſt of two layers: the firſt of which is to be coarſe and capable of hardening to the higheſt degree; the ſecond is to conſiſt of flint powder lime and lime water, and is to laid on very thin, and finely ſmoothed. To give a rich colour together with a ſmooth ſurface, to our beſt

beſt incruſtation, we muſt uſe, in the place of flint powder, for the finiſhing coat, the coloured powder of ſands, or ſtones, or glaſſes; and introduce as much of the colouring ingredients uſed in painting, as will be ſufficient to give the required appearance, avoiding thoſe which are ſpoiled by lime.

To my eye, the warm white, or coloured ſtucco which is not quite ſmooth, is the pleaſanteſt: but thoſe who prefer the ſmootheſt, may have it made at a moderate expence, in this laſt-mentioned method, in which the uſeful and ſolid part of it, contributes to the ſupport and duration of the weaker ornamental coat, which thus circumſtanced is likely to preſerve its beauty for a very long time, although it might, in the weather, be impaied in three or four years.

SECTION

SECTION XXI.

Experiments ſhewing the Effects of common Wood-aſhes, calcined or purer Wood-aſhes, elixated Aſhes, Charcoal Powder, Sea Coal-aſhes, and powdered Coak, in Mortar; and Obſervations on their integrant Parts, and the Differences between them and the Powders of other Bodies.

THE aſhes of wood and ſea-coal are frequently mixed with mortar, or uſed in the place of ſand, in laying tiled floors, and even in external incruſtations. Some workmen ſay they are uſed in the former caſe to ſave ſand; others that they ſerve to reſiſt moiſture; and thoſe who ſeem to be the beſt informed affirm, that they haſten the drying and induration, and prevent the cracking of mortar which is laid very thick in order to fill the depreſſions of walls which are to be ſtuccoed; and that they are uſed in finer incruſtations with the ſole view of preventing cracks.

THE

The aſhes of the ſame kind of wood differ, according to the circumſtances in which they are formed, even upon the ſame hearth, not only in colour, but in other particulars known to chemiſts, which I ſhall attend to preſently. As the ſeparation of theſe different ſorts of aſhes is not practicable at a moderate expence, and never is attempted by the workmen, I contented myſelf, at firſt, with procuring the aſhes of cleft pollards burned on a hearth, and with ſifting the whole quantity of them, to free the finer part from the fragments and coarſe powder of charred wood which formed a great part of the bulk of them. The ſifted aſhes were grey inclining to brown, ſtrongly alkaline to the taſte, and viewed through a convex lens, were found to contain a conſiderable quantity of fine charcoal-powder, which I eſtimated at one ſixth or more of their bulk.

To learn the effect of the purer aſhes, or of the more dephlogiſticated earthy and ſaline parts ſeparated from the charcoal, I took about a gallon of the ſifted aſhes, and burned them on a teſt in a reverberatory furnace, with a heat not exceeding that of a culinary

fire, taking care to accelerate the combuſtion of the charcoal powder contained in them and render it equable thro' the whole heap, by ſtirring it, and preſenting freſh ſurfaces to the air, until the whole was rendered incombuſtible. After this proceſs, the powder, which I ſhall call calcined wood aſhes, was rather brown than grey, and retained its ſaline taſte.

On trying the ſifted wood aſhes in my beſt mortar, and in other mixtures of ſand and lime, I found that they gave the cement a ſpongy texture, and enabled it to dry without cracking, when the lime was not uſed in exceſſive quantity; but that they prevented it from acquiring the hardneſs of mortar made of lime and ſand only: ſo that the advantages which they promiſed to afford in certain circumſtances, appeared to be counterbalanced by the permanent weakneſs induced by them; which latter effect was the greater as the quantity of the aſhes came nearer to equal that of the lime.

The calcined wood aſhes likewiſe prevented the mortar from cracking, without making it ſo ſpongy: but they manifeſtly impeded

peded the induration of it, and diſpoſed it to be injured by rain, in the ſame manner as ſmall quantities of alkali were found to do.

On a ſtrict compariſon, the calcined wood aſhes, which we may conſider as aſhes freed from charcoal powder, appeared to be much more injurious than the uncalcined. This I imputed to the greater quantity of alkali in the former, which is hurtful in a double capacity; firſt as a ſaline body; and ſecondly as a compound which yields its aciculous gas to lime, in the inſtant of mixture, and conſequently impairs the cement.

Mortar made with bad lime in the uſual proportions may nevertheleſs be improved by ſifted wood aſhes; for the coal and earthy part of theſe, if they were only equivalent to ſo much ſand, render it leſs liable to crack; and the bad effects of the alkali may be greatly overbalanced by this advantage, in an incruſtation which is required to be rather uniform and ſecure from cracking, than hard and durable in the higheſt degree.

I MUST not omit this opportunity of obſerving that calcined wood aſhes, and even the ſifted freſh wood aſhes, improve plaiſter of Paris in hardneſs, to a very great degree, if it be kept in a dry place. The ſolution of this phænomenon is not difficult.

ANY perſon who intends to repeat my experiments on calcined wood-aſhes, ought to take care that they be not calcined with a ſtronger heat than I deſcribed; for if he exceeds this, the aſhes, after the ſigns of their combuſtion have ceaſed, will ſmoak ſtrongly, a part of the ſaline matter being ſublimed in the mean time; and the remaining earthy and ſaline portion will form a light grey or brown ſemivitrified gritty powder, or will concrete into lumps. This matter will then be found inſipid and equivalent to ſand, in mortar, as I have experienced; for it differs as much from wood aſhes, as the powder of potters-ſtone-ware differs from the raw clay.

WHILST I was employed in theſe experiments, the following thoughts occurred to me. The aſhes uſed by the workmen, being paſſed through a coarſe ſieve, may conſiſt for

for the greater part, of charcoal, which afterwards is beaten finer in making the mortar: The aſhes uſed by builders whoſe durable works authorized this practice, might have been the refuſe of manufactories of potaſh, in which the ſaline matter is always carefully extracted from them; and charcoal powder or elixated aſhes may greatly improve mortar, altho' aſhes finely ſifted and replete with ſalts ſhould impair it. I therefore boiled my calcined wood-aſhes in water, and repeated this operation twice in freſh water; knowing that one elixation does not free the aſhes perfectly from the ſaline matter: I then dried the inſipid aſhes thoroughly, and uſed them in this ſtate, under the name of elixated wood-aſhes. At the ſame time I provided charcoal powder ſifted thro' the ſame ſieve which I uſed for the wood-aſhes.

After a great number of experiments made in the uſual manner with the elixated aſhes, I found that they rendered the mortar ſpongy, diſpoſed it to dry and harden quickly, and prevented it from cracking, more effectually than the like additional quantity of ſand would do it. They did not ap-

pear to induce the defects attending saline bodies in mortar; they only made it weaker, as the quantity of the elixated ashes was greater relatively to that of the sand or lime. This weakness, however, was not such as the unwashed ashes or saline bodies produce, but rather of the kind which I pointed out in those parts of the foregoing sections, wherein I endeavoured to shew, that cementious masses resist edged instruments or any force tending to break them, the more weakly, as they contain more of the softer and brittler calcareous matter, or as softer grains are substituted for a part of the sand.

In every comparison of the specimens containing unwashed wood-ashes, with those in which the elixated ashes were mixed in the same proportions, it clearly appeared that the latter are to be preferred; and that neither of them ought ever to exceed half the quantity of lime, in good mortar.

As flint powder and other earthy powders were found to dispose mortar to crack, I could not conceive how the elixated wood-ashes operated so effectually in preventing this

this defect, until I examined them attentively, and found them to differ from the other powders in two particulars. Elixated wood-aſhes contain very little powder of the finer kind; they feel gritty between the fingers, and appear to conſiſt of ragged ſpongy ſmall grains compreſſible to a conſiderable degree in the heap. How a powder thus conditioned prevents the cracking of mortar or otherwiſe improves it, I ſhall attempt to explain, after ſtating other facts upon which my notions of this ſubject are founded.

CHARCOAL powder had the ſame effects as elixated wood-aſhes, with theſe differences only, that the cements containing the larger quantities of charcoal powder could be more eaſily cut, and were of a bluer colour, than thoſe containing the like quantities of elixated wood-aſhes. The powder which I uſed was ſifted like the aſhes; and, viewed through a microſcope, anſwered to the deſcription lately given of elixated aſhes.

THE ſkreened aſhes of Newcaſtle coal conſiſt chiefly of charred coal or coak, and as they contain very little ſaline matter, are inſipid.

When I reduced them to powder, and paſſed them thro' the ſieve, they anſwered to the deſcription given of elixated wood aſhes, and produced nearly the ſame effects in mortar. They did not weaken it ſo much as charcoal powder had done; which I impute to the greater hardneſs of the ſmall grains of coak.

In all theſe compariſons, it is to be underſtood that I made them at the ſame periods of the induration of the ſeveral ſpecimens.

From theſe experiments I conclude that, where a choice can be made, theſe powders are eligible in this order; elixated wood aſhes freed from the fineſt powder in waſhing, firſt; powdered coak or ſea coal cinders, next; charcoal powder next; rough wood aſhes powdered, laſt: But well burned fine unwaſhed wood-aſhes ought not to be uſed at all in external cementious work or incruſtation.

The laſt of theſe gives a diſagreeable grey or duſky colour to the cement; and the others, a blueiſh or ſlate colour, ſtill more offenſive to the eye; for which reaſon they

are

are unfit for any work that is not hid from the view.

As my reader may not fully underſtand what I briefly mentioned concerning the ſenſible difference between theſe laſt examined powders, and others noticed in the preceding ſections, I will thus exemplify my notions. Wood conſiſts of watery and volatile parts which are expelled by heat, and of fixed parts which conſtitute the charcoal: and charred wood, which greedily imbibes air or water in great quantity, may be conſidered as an aſſemblage of capillary tubes of divers figures and ſizes. So we may likewiſe conſider the fragments of charcoal, and each viſible grain of its powder. But as the moſt brittle bodies are flexible when they are made ſufficiently thin, the charcoal powder is an aſſemblage of ſmall flexible or compreſſible tubulated bodies.

As the charcoal which is the more fixed and ſolid baſis of wood, is ſpongy after the juices are expelled in charring; ſo the aſhes of charred wood are, after the elixation, an aſſemblage of ſpongy or tubulated grains out of

of which the phlogiſtic matter has eſcaped during the combuſtion: and the texture of theſe grains differs from that of the grains of fine ſand or of flint powder, in the ſame manner, if not in the ſame degree, as the texture of ſponge differs from that of a flint. And we may conceive the unwaſhed wood aſhes, as a heap of ſmall ſpongy bodies clogged with alkaline ſalt.

Upon the ſame grounds, the relation of coak or ſea-coal-cinders to the raw coal, is analogous to that which charcoal bears to wood, or ſpongy pumice ſtone to porphyry; and transferring theſe obſervations to bones, and conſidering the ſmaller veſſels and finer texture of them than of wood, we ſhall find the powder of charred bones to conſiſt of tubulated or ſpongy bodies like thoſe of charcoal powder, but pervious by ſlenderer and harder tubes; and bone-aſh, which is the gritty powder of well burnt bones, to have the ſame relation to the charred bones, which elixated wood-aſhes have to charcoal powder.

Thus I have thought of theſe ſubſtances, after having obſerved what happens to them in

in the preparation; examined them by a microſcope; experienced their effects to be ſo different from thoſe of fineſt ſand, or powdered ſtones, in mortar; and finally diſcovered, by repeated experiments, the detail of which is not now neceſſary, that ſemivitrification, which deſtroys the ſpongy texture, and levigation, which breaks theſe ſpongy grains down to the particles of which they are conſtructed, render charcoal powder, wood-aſhes, powdered ſea-coal-cinders, and others of the like kind, incapable of acting in the manner deſcribed, in calcareous cements.

All theſe things being conſidered, I impute the effects of theſe aſhes, or powders, to the tubulated ſtructure and compreſſibility of the integrant parts of them; and in the next ſection I ſhall offer all that I have attempted further, theoretically or practically, relative to this ſubject.

SECTION

SECTION XXII.

Experiments ſhewing the Effects of white and grey Bone aſhes, and the Powder of Charred Bones; and Theory of the Agency of theſe in the beſt calcareous Cements.

LONG before I had tried all the powders heretofore mentioned, I uſed bone-aſh in many experiments, and ſaw the effects of it in mortar. For the ſake of brevity and perſpicuity I reſerved the relation of them for this ſection: and in order to ſhew more clearly the analogy in texture, between bone-aſhes and the powders lately mentioned, and to ſuggeſt the means of procuring them in any part of this country, I will premiſe a ſketch of the moſt profitable proceſſes by which they are prepared, at a moderate price not much exceeding that of good ſtone-lime.

THE

The bones collected in great cities, are broken to ſmall fragments in a mill, and boiled in water, in order to extricate and ſave the oil of them. They are then put into a large iron ſtill, through an aperture which is ſtopped up cloſely after the charge is made. The ſtill, which opens into an apparatus of refrigeratory veſſels, is heated gradually to redneſs, until all the volatile alkali, commonly called ſpirit and ſalt of hartſhorn, is expelled from them, together with empyreumatic oil, water, and certain elaſtic inviſible fluids: The alkali, being the only valuable article amongſt theſe, is retained and condenſed in the refrigeratory tubes and veſſels with all poſſible care, whilſt the elaſtic fluids, leſt they ſhould burſt the veſſels, are ſuffered to eſcape in places diſtant from the fire or the flame of candles, becauſe they are combuſtible, and if they catch fire whilſt air remains in the condenſing veſſels, explode like gunpowder.

The bones thus heated without being expoſed to the air, are charred to blackneſs, but ſtill remain combuſtible. When they are required in this ſtate, the iron ſtill is kept

kept closed until they cool, and then the blackest of them are ground to fine powder, which is used as a substitute for ivory black, which is prepared in the same way from ivory. The coarser powder of these, is what I understand by powder of charred bones. But when this is not the manufacturer's design, the door of the iron still is opened whilst it is hot, and the charred bones, which flame and burn when they meet the air, are thrown into a kind of kiln, at the bottom of which the air can freely enter, and maintain the combustion, until the bones are burned to whiteness, for the greater part. The white fragments are picked, and rather bruised, than ground, to a gritty powder, by a millstone which rolls on them vertically over an inclined circular plane. This powder passed thro' a sieve is called bone-ashes, which are much used in metallurgy, and fitter for our purposes in incrustations, than the powder of burned bones ground as pigments are. The fragments which have not been thoroughly burned in the kiln, form a dark grey powder; and mixtures of the white and grey burned bones afford bone-ashes of the lighter grey colours.

 THE

THE whole quantity of bone-aſhes, which is to be uſed in the ſame incruſtation, ought to be well mixed; for it is impoſſible to ſort the well burned or the grey bones ſo accurately as to ſecure an unity of colour in the parcels of powder which are ſucceſſively prepared, and a very ſmall variation of colour will be ſeen in the incruſtation.

MR. JOHN OLIVER of Hoxton, who is a very liberal and ingenious artiſt, prepares bone-aſhes, judiciouſly adapted to the purpoſes which I am now to mention, at a very low price, as well as the coarſer kind which is uſed in making cupels and teſts by the refiners. I ſhall diſtinguiſh the former by the name of ſorted bone-aſhes; becauſe they are freed from the fineſt and the coarſeſt parts of the latter.

As I knew that bone-aſhes conſiſt chiefly of calcareous earth, and may be reduced to lime, by diſſolving them in acids, precipitating the ſolution by alkalies, waſhing the precipitate perfectly and then burning it, I tried them with ſand in different ways, in order to learn how far they reſemble lime in their cementing

menting properties; and found that the ſorted bone-aſhes had very little effect; but that compoſitions made with the levigated powder of theſe and ſand and water, were nearly equal in hardneſs to thoſe made with whiting and ſand kneaded with water in the ſame proportions, and were not ſo liable to crack. Hence I inferred that bone-aſhes, of which five-ſixths are calcareous earth, could not improve mortar by any augmentation of the cementing powers of the lime, although they might be uſeful in other reſpects, and that they could not ſupply the defect of lime in quantity or quality.

In the courſe of two years I made ſo many experiments with bone-aſhes mixed in mortar compoſed of lime ſand and lime water, in different proportions, and of theſe with divers other ingredients, that I may venture to ſay I attained a thorough knowledge of their effects, and need not heſitate to relate them in the ſtyle of precept.

The ſorted bone-aſhes, mixed with mortar in any quantity not exceeding that of the lime, diſpoſe the cement to ſet ſpeedily without

out cracking; and effectually ſecure it from cracking, if it does not contain lime in ſuperfluous quantity: They likewiſe give a texture which is the more ſpongy as the quantity of the bone-aſhes is greater; and they accelerate the induration of it through the whole maſs.

THE ſorted bone-aſhes encreaſe the plaſticity of freſh mortar which is made with the ſmaller quantities of lime in order to ſecure the work from fiſſures; and thus they are uſeful in a triple view, in external incruſtations; by facilitating the operation of plaiſtering, by preventing cracks, and by bringing the incruſtation quickly to a ſtate in which it is not eaſily injured by unexpected rain.

WHEN the ſorted bone-aſhes exceed the lime in quantity, they ſenſibly injure the cement, by rendering it weaker. How theſe aſhes, which are not equivalent to ſand in the hardneſs of their grains, nor to lime in their cementing powers, operate to weaken the cement, may eaſily be conceived, in con-

ſequence of the obſervations made in the ninth, twelfth and thirteenth ſections.

When the ſorted bone-aſhes are mixed in mortar in the quantity of one-fourth of the lime, they improve the plaſticity, if the mortar be ſhort, and they produce the deſireable effects above mentioned in a ſenſible degree, without weakening the cement in the ſame proportion. As a ſmaller quantity of them ſeems to be uſeleſs, and a greater quantity than that of the lime injurious, the following rules are to be obſerved.

When the artiſt is more ſolicitous to ſecure an incruſtation from the effects of hot weather, to finiſh it quickly, to hide the traces of brick-work which are apt to appear thro' it, and to guard it againſt rain, than to make it hard and durable in the higheſt degree; he is to uſe as much of ſorted bone-aſhes as of lime: When the ſeaſon, expoſure, and other circumſtances permit him to attend ſolely to the true excellence and duration of his work, he is to uſe, in our beſt calcareous cement, only one part of the ſorted bone-aſhes for every four parts of lime. By theſe rules

rules he may chuſe intermediate quantities adapted to his purpoſes.

THE coarſer bone-aſhes uſed in making cupels and teſts, do not go ſo far, ſo the workmen expreſs themſelves, or do not operate ſo effectually, as the ſorted aſhes, in equal quantities of them by weight; and finer or levigated bone-aſhes are rather injurious than uſeful in the coarſer cements.

THE black powder of charred bones, and grey bone-aſhes have nearly the ſame effects as ſorted bone-aſhes have, when the powder of them is ſorted in the ſame manner; excepting what relates to colour.

THESE obſervations on bone-aſhes were made before the expiration of 1777, on ſpecimens of mortar laid on tiles, and ſmall pieces of incruſtation made on the walls of my houſe and on the fence-walls behind it: But they were not thoroughly confirmed until a compariſon was made between large incruſtations laid in trying aſpects and containing bone-aſhes, with thoſe made cloſe by them of my beſt mortar, in the year 1778;

when I diſcovered the difficulty expreſſed in the fourteenth ſection, of making extenſive incruſtations, in certain circumſtances, ſo free from defects, as the ſmaller ones were which I had made at home.

In this laſt mentioned year I was favoured by Mr. James Wyatt of Queen-Ann-ſtreet Cavendiſh-ſquare, the celebrated architect of the Pantheon, and by his brother Samuel Wyatt of Berwick-ſtreet, who is a very eminent builder, with the beſt opportunities of making theſe compariſons: for they ordered the plaiſterers employed under them to apply my compoſitions in a workman-like manner, in different aſpects and in large quantity, and thus enabled me to judge truly of the merits of them.

By the analogy of bone-aſhes to cinders or aſhes of other bodies, by the effects of them in my experiments, and by the obſervations which I have made on capital houſes and garden walls which have been fronted or entirely ſtuccoed with my cement, ſome in the months of October November and December in the year 1778, others in the Spring,

Spring, the hotteſt weather, and the Autumn of 1779; I have been led into the following opinions concerning the agency of bone-aſhes in calcareous cements.

THE mortar which contains bone-aſhes, partakes in ſome degree of the compreſſibility and ſpongineſs of their grains, and is the leſs liable to crack in ſetting, for the ſame reaſon that ſpongineſs is, in any other body, an effectual preventative of fiſſures in drying; or becauſe, any contraction of the lime paſte, in conſequence of the exhalation of its water, is confined to the circuit of the ſpongy grains compreſſed in beating trowelling and floating the cement, and is thereby prevented from running longitudinally to form fiſſures. The ſame texture of bone-aſhes contributes to this effect, or cauſes it, upon other principles which are leſs exceptionable. There is no reaſon to doubt that bone-aſhes, whoſe grains are tubulated in all poſſible directions, which greedily imbibe water and emit air, and which render the mortar in which they are mixed manifeſtly bibulous, facilitate the entry of acidulous gas into the cement; and that this matter entering as faſt

as the water exhales, occupies the place of the water in the cement, and by preventing the contraction of it, prevents fiſſures. The ſpeedy induration of the cement, which implies a quick or copious acceſſion of acidulous gas, according to our experience, is a proof of this agency of bone-aſhes, as well as an effect deducible from their texture; and from theſe premiſes we may eaſily conceive how they accelerate the ſetting of calcareous incruſtations, and tend to ſecure them from the injuries of variable weather.

THESE properties of bone-aſhes render them peculiarly uſeful in incruſtations made within doors on principal walls; and the admixture of them in half the quantity of the lime, or in a greater quantity, is the improvement which I pointed out in the twentieth ſection, whereby the damp, which diſfigures the common incruſtations made in the circumſtances there deſcribed, may be obviated, without our incurring the expence of lath-work.

THOSE who know that one-ſixth part of charred bones, or about one-tenth part of well

well burned bones, is phoſphoric acid, may have ſome doubt concerning the duration of a cement in which they are mixed in large quantity, unleſs they conſider that the ſtrength of the cement does not depend on them, and that it is impoſſible for the phoſphoric acid to quit the lime of bone-aſhes, in order to diſſolve the ſaturated lime of the cement. Tho' the bone-aſhes ſhould periſh in a century, which is not probable, the cement is not likely to fail on this account, provided the quantity of them is not exceſſive.

Thus I ſurmounted the difficulties mentioned in the fourteenth ſection, and made my beſt calcareous cement applicable in all cementitious and cruſtaceous works external or internal, without inducing in it any diſagreeable colour or other imperfection.

SECTION XXIII.

The Specification made in Conſequence of Letters Patent, illuſtrated with Notes.

IN order to guard againſt abuſes, and to make ſome compenſation for the expences and riſques of the artiſts who publicly and boldly executed, on the great ſcale, what I had deſigned; I ſecured an excluſive right in my cement, by virtue of his majeſty's letters patent, on the eighth of January 1779: I authorized Mr. James Wyatt the architect of Queen-Ann-ſtreet Cavendiſh-Square, to uſe it in the fulleſt extent, knowing that he, by his knowledge of this ſubject and his diſtinguiſhed taſte in architecture, will unite in it all the advantages of duration and elegance; I likewiſe extended this right to Samuel Wyatt the builder in Berwick-ſtreet Soho, who is well inſtructed, and provided with the means of executing any work with this cement, in the higheſt perfection: And I intend to reſerve this priviledge to them, until

til the public convenience requires that it ſhould be extended to others, who are capable of making the ſame diſpoſitions for the benefit of their employers, and for preſerving the reputation of my invention free from the uſual exactions of monopoliſts and the abuſes of under-jobbers,

As the ſpecification of theſe letters patent comprehends the moſt uſeful practical inſtructions deduced from the foregoing experiments and obſervations, and may ſerve as a conciſe recapitulation, I ſubjoin a tranſcript of it.

SPECIFICATION.

To all to whom theſe preſents ſhall come &c.

" Now know ye that in compliance with " the ſaid proviſoe, I the ſaid B. H. do here- " by declare that my invention of a water " cement or ſtucco, for building repairing and " plaſtering walls, and for other purpoſes, is " deſcribed in the manner following (that is " to ſay) drift ſand, or quarry[a] ſand, which

[a] This is commonly called pit-ſand.

" conſiſts

" conſiſts chiefly of hard quartoſe flat faced[2]
" grains with ſharp angles; which is the
" freeſt, or may be moſt eaſily freed by
" waſhing, from clay, ſalts, and calcareous
" gypſeous or other grains leſs hard and
" durable than quartz; which contains the
" ſmalleſt quantity of pyrites or heavy me-
" tallic matter inſeparable by waſhing; and
" which ſuffers the ſmalleſt diminution of
" its bulk in waſhing in the following
" manner, is to be preferred before any
" other[3]. And where a coarſe and a fine
" ſand of this kind, and correſponding in
" the ſize of their grains with the coarſe
" and fine ſands hereafter deſcribed, cannot
" be eaſily procured, let ſuch ſand of the
" foregoing quality be choſen, as may be
" ſorted and cleanſed in the following
" manner.

" LET the ſand be ſifted in ſtreaming
" clear water, through a ſieve which ſhall
" give paſſage to all ſuch grains as do not

[2] THE twelfth ſection treats of this.

[3] THE reaſons of this preference are given in the fifteenth, ſixteenth, nineteenth, and twentieth ſections.

" exceed

" exceed one ſixteenth of an inch in dia-
" meter; and let the ſtream of water and
" the ſifting be regulated ſo that all the ſand
" which is much finer than the Lynn-ſand
" commonly uſed in the London glaſs-houſes,
" together with clay and every other matter
" ſpecifically lighter than ſand, may be waſhed[4]
" away with the ſtream, whilſt the purer and
" coarſer ſand, which paſſes thro' the ſieve,
" ſubſides in a convenient receptacle, and
" whilſt the coarſe rubbiſh and ſhingle[5] re-
" main on the ſieve, to be rejected.

" LET the ſand which thus ſubſides in
" the receptacle, be waſhed in clean ſtream-
" ing water, through a finer ſieve, ſo as to
" be further cleanſed and ſorted into two
" parcels; a coarſer, which will remain in
" the ſieve which is to give paſſage to ſuch
" grains of ſand only as are leſs than one
" thirtieth of an inch in diameter, and
" which is to be ſaved apart under the name

[4] THE grounds of this treatment appear in the twelfth and thirteenth ſection.

[5] I find that I have uſed this word improperly, on bad authority. The reader is requeſted to read rubble inſtead of ſhingle throughout this ſpecification.

" of

" of coarſe ſand; and a finer, which will " paſs through the ſieve and ſubſide in the " water, and which is to be ſaved apart " under the name of fine ſand.—Let the " coarſe and the fine ſand be dried ſepa- " rately, either in the ſun, or on a clean iron " plate ſet on a convenient furnace, in the " manner of a ſand heat [6].

" Let lime be choſen [7] which is ſtone lime, " which heats the moſt in ſlaking, and ſlakes " the

[6] The ſand ought to be ſtirred up continually until it is dried, and is then to be taken off; for otherwiſe the evaporation will be very ſlow, and the ſand which lies next the iron plate, by being overheated, will be diſcoloured.

[7] The grounds of the inſtructions comprized in this paragraph, appear in the ſecond, fourth, fifth and eleventh ſections. The preference given to ſtone lime is founded on the preſent practice in the burning of lime, and on the cloſer texture of it, which prevents it from being ſo ſoon injured by expoſure to the air, as the more ſpongy chalk lime is; not on the popular notion that ſtone lime has ſomething in it whereby it excels the beſt chalk in the cementing properties. The real difference between theſe will be ſhewen in the next ſection.

The gypſum contained in lime ſtone remains unaltered or very little altered in the lime, after the burning; but it is not to be expected that clay or martial matter ſhould be found in their native ſtate, in well burned lime; for they concrete or vitrifie with a part of the calcareous earth, and conſtitute the hard grains

" the quickeſt when duly watered; which
" is the freſheſt made and cloſeſt kept;
" which diſſolves in diſtilled vinegar with
" the leaſt effervescence, and leaves the
" ſmalleſt reſidue inſoluble, and in this re-
" ſidue the ſmalleſt quantity of clay gypſum
" or martial matter.

" LET the lime choſen according to theſe
" important rules, be put in a braſs-wired
" ſieve to the quantity of fourteen pounds.
" Let the ſieve be finer than either of the
" foregoing; the finer, the better it will be:
" Let the lime be ſlaked[s] by plunging it in
" a butt

grains or lumps, which remain undiſſolved in weak acids, or are ſeperable from the ſlaked lime by ſifting it immediately through a ſieve.

[s] THIS method of impregnating the water with lime is not the only one which may be adopted. It is however preferred before others, becauſe the water clears the ſooner in conſequence of its being warmed by the ſlaking lime, and the gypſeous part of the lime does not diffuſe itſelf in the water ſo freely in this way, as it does when the lime is ſlaked to fine powder in the common method and is then blended with the water; for the gypſeous part of the lime ſlakes, at firſt, into grains, rather than into fine powder, and will remain on the ſieve, after the pure lime has paſſed through, long enough to admit of the intended ſeparation; but when the lime is otherwiſe ſlaked, the gypſeous grains have time to ſlake to a finer powder, and paſſing

" a butt filled with ſoft water and raiſing it
" out quickly and ſuffering it to heat and
" fume, and by repeating this plunging and
" raiſing alternately and agitating the lime,
" until it be made to paſs through the ſieve
" into the water; and let the part of the
" lime which does not eaſily paſs through the
" ſieve be rejected: and let freſh portions of
" the lime be thus uſed, until as many[9]
" ounces of lime have paſſed through the
" ſieve, as there are quarts of water in the butt.
" Let the water thus impregnated ſtand in the
" butt cloſely covered[10] until it becomes clear;
" and through wooden[11] cocks placed at dif-
" ferent heights in the butt, let the clear liquor

paſſing through the ſieve, diſſolve in the water along with the lime. I have imagined that other advantages attended this method of preparing the lime water, but I cannot yet ſpeak of them with preciſion.

[9] If the water contains no more acidulous gas than is uſually found in river or rain water, a fourth part of this quantity of lime, or leſs, will be ſufficient.

[10] The calcareous cruſt which forms on the ſurface of the water ought not to be broke, for it aſſiſts in excluding the air and preventing the abſorption of acidulous gas whereby the lime water is ſpoiled.

[11] Braſs cocks are apt to colour a part of the liquor.

" be

" be drawn off as faſt[12] and as low as the
" lime ſubſides, for uſe. This clear liquor I
" call the cementing liquor[13]. The freer the
" water is from ſaline matter, the better will
" be the cementing liquor made with it.

" Let fifty-ſix pounds of the aforeſaid
" choſen lime be ſlaked, by gradually ſprinkl-
" ing on it, and eſpecially on the unſlaked
" pieces, the cementing liquor, in a cloſe[14]
" clean place. Let the ſlaked part be im-
" mediately

[12] Lime water cannot be kept many days unimpaired, in any veſſels that are not perfectly air-light. If the liquor be drawn off before it cleats, it will contain whiting, which is injurious; and if it be not inſtantly uſed, after it is drawn limpid from the butt into open veſſels, it will grow turbid again, and depoſite the lime changed to whiting by the gas abſorbed from the air. The calcareous matter which ſubſides in the butt, reſembles whiting the more nearly, as the lime has been more ſparingly employed; in the contrary circumſtances, it approaches to the nature of lime; and in the intermediate ſtate, it is fit for the common compoſition of the plaiſterers for inſide ſtucco.

[13] At the time of writing this ſpecification I preferred this term before that of lime-water, on grounds which I had not ſufficiently examined.

[14] The vapour which ariſes in the ſlaking of the lime contributes greatly to the ſlaking of theſe pieces which lie in its way; and an unneceſſary waſte of the liquor is prevented, by applying it to the lime heaped in a pit or in a veſſel which may reſtrain

" mediately [15] ſifted through the laſt men-
" tioned fine braſs-wired ſieve: Let the lime
" which paſſes be uſed inſtantly or kept in
" air-tight veſſels, and let the part of the lime
" which does not paſs through the ſieve, be
" rejected [16].—This finer richer part of the
" lime which paſſes through the ſieve, I call
" purified lime.

" LET bone-aſh be prepared [17] in the uſual
" manner by grinding the whiteſt burnt
" bones, but let it be ſifted to be much finer

reſtrain the iſſue of the vapour, and direct it through the maſs. If more of the liquor be uſed than is neceſſary to ſlake the lime, it will create error in weighing the ſlaked powder, and will prevent a part of it from paſſing freely through the ſieve. The liquid is therefore to be uſed ſparingly, and the lime which has eſcaped its action is to be ſprinkled apart with freſh liquor.

[15] WHEN the aggregation of the lumps of lime is thus broken, it is impared much ſooner than it is in the former ſtate, becauſe the air more freely pervades it. This is ſhewn in the fifth ſection.

[16] BECAUSE it conſiſts of heterogeneous matter, or of ill burnt lime; which laſt will ſlake and paſs through the ſieve, if the lime be not immediately ſifted after the ſlaking, agreeable to the text. The reaſon of this may be drawn from the fourth ſection.

[17] THIS art is taught in the twenty-ſecond ſection.

" than

" than the bone-aſh commonly ſold for " making cupels.

" THE moſt eligible materials for making " my cement being thus prepared: Take " fifty-ſix pounds of the coarſe ſand and " forty-two pounds of the fine ſand; mix " them on a large plank of hard wood " placed horizontally; then ſpread the ſand " ſo that it may ſtand to the height of ſix " inches with a flat ſurface on the plank; " wet it with the cementing liquor; and let " any ſuperfluous [18] quantity of the liquor, " which the ſand in the condition deſcribed " cannot retain, flow away off the plank. " To the wetted ſand add fourteen pounds " of the purified lime in ſeveral ſucceſſive " portions, mixing and beating them up toge- " ther in the mean time with the inſtruments " generally uſed in making fine mortar: " then add fourteen pounds of the bone-aſh " in ſucceſſive portions, mixing and beating " all together. The quicker and the more " perfectly theſe materials are mixed and " beaten together, and the ſooner the ce-

[18] THE grounds of this practice are ſhewn in the twelfth ſection.

" ment thus formed is uſed, the better [19] it " will be. This I call the water cement " coarſe grained, which is to be applied in " building, pointing, plaiſtering, ſtuccoing, " or other work, as mortar and ſtucco now " are; with this difference chiefly, that as " this cement is ſhorter than mortar or com- " mon ſtucco and dries ſooner, it ought to " be worked expeditiouſly in all caſes, and " in ſtuccoing it ought to be laid on by ſlid- " ing the trowel upwards on it; that the " materials uſed along with this cement " in building, or the ground on which it is " to be laid in ſtuccoing, ought to be well " wetted [20] with the cementing liquor, in

[19] THESE proportions are intended for a cement made with ſharp ſand, for incruſtation in expoſed ſituations, where it is neceſſary to guard againſt the effects of hot weather and rain. In general half this quantity of bone-aſhes will be found ſufficient; and altho the incruſtation in this latter caſe will not harden deeply ſo ſoon, it will be ultimately ſtronger provided the weather be favourable.

THE injuries which lime and mortar ſuſtain, by expoſure to the air, before the cement is finally placed in a quieſcent ſtate, appear in many parts of the foregoing pages; and therefore our cement is the worſe for being long beaten, but the better as it is quickly beaten untill the mixture is effected, and no longer.

[20] SEE ſection vii. and page 75.

" the

" the inſtant of laying on the cement; and
" that the cementing liquor is to be uſed when
" it is neceſſary to moiſten the cement, or
" when a liquid is required to facilitate the
" floating of the cement.

" WHEN ſuch cement is required to be
" of a finer texture; take ninety-eight pounds
" of the fine ſand, wet it with the cementing
" liquor and mix it with the purified lime
" and the bone-aſh in the quantities and in
" the manner above deſcribed, with this
" difference only, that fifteen pounds of
" lime, or[21] thereabouts, are to be uſed inſtead
" of fourteen pounds, if the greater part of
" the ſand be as fine as Lynn ſand. This I
" call water cement fine grained. It is to
" be uſed in giving the laſt coating or the fi-
" niſh to any work intended to imitate the
" finer grained ſtones or ſtucco. But it may
" be applied to all the uſes of the water ce-
" ment coarſe grained, and in the ſame
" manner.

[21] SEE ſection xiii. The quantity of bone-aſhes is not to be increaſed with that of the lime, for the reaſon given in page 176; but it is to be leſſened as the expoſure and purpoſes of the work will admit. See ſection xxii.

" When for any of the foregoing pur-
" poſes of pointing, building, &c. ſuch a
" cement is required much cheaper and
" coarſer grained, then, much coarſer clean
" ſand than the foregoing coarſe ſand, or well
" waſhed fine [22] ſhingle is to be provided.
" Of this coarſeſt ſand or ſhingle take fif-
" ty-ſix pounds, of the foregoing coarſe ſand
" twenty-eight pounds and of the fine ſand
" fourteen pounds; and after mixing theſe
" and wetting them with the cementing li-
" quor in the foregoing manner, add 14
" pounds, or ſomewhat leſs, of the [23] puri-
" fied lime, and then fourteen pounds or
" ſomewhat leſs of the bone-aſh, mixing
" them together in the manner already de-
" ſcribed. When my cement is required
" to be white, white ſand, white lime, and
" the whiteſt bone-aſh are to be choſen.
" Grey ſand and grey bone-aſh formed of
" half burnt bones, are to be choſen to make
" the cement grey; and any other [24] colour

[22] Rubble.

[23] Because leſs lime is neceſſary as the ſand is coarſer. Section xii. and xiii.

[24] The outlines of theſe arts are given in ſection xx.

" of

" of the cement is obtained, either by chuſ-
" ing coloured ſand, or by the admixture of
" the neceſſary quantity of coloured talc in
" powder, or of coloured vitreous or metal-
" lic powders, or other durable [25] colouring
" ingredients commonly uſed in paint.

" To the end that ſuch a water cement
" as I have deſcribed may be made as uſe-
" ful as is poſſible in all circumſtances; and
" that no perſon may imagine that my
" claim and right under theſe Letters Pa-
" tent may be eluded by divers variations
" which may be made in the foregoing pro-
" ceſs without producing any notable de-
" fect in the cement; and to the end that
" the principles of this art as well as the art
" itſelf of making my cement, may be ga-
" thered from this ſpecification and perpe-
" tuated to the public, I ſhall add the fol-
" lowing obſervations.

[25] The known chemical properties of the ſeveral finer ingredients uſed in paint or water colouring, and the experienced effects of the materials mentioned in the fifteenth, ſixteenth, ſeventeenth, eighteenth, nineteenth and twentieth ſections, are ſufficient to direct the artiſt in the choice of thoſe things which will induce colour, with the ſmalleſt injury to the incruſtation.

" THIS my water cement, whether the " coarſe or fine grained, is applicable in " forming artificial ſtone, by making alter- " nate layers of the cement and of flint, hard " ſtone, or brick, in moulds of the figure " of the intended ſtone, and by expoſing the " maſſes ſo formed, to the open[26] air to " harden.

" WHEN ſuch cement is required for " water[27] fences, two thirds of the preſcribed

[26] BUT they muſt not be expoſed to the rain, until they are almoſt as ſtrong as freſh Portland ſtone; and even then they ought to be ſheltered from it, as much as the circumſtances will admit. See pages 68, 69, 114. Theſe ſtones may be made very hard and beautiful, with a ſmall expence of bone-aſh, by ſoaking them, after they have dried thoroughly and hardened, in the lime-liquor, and repeating this proceſs twice or thrice, at diſtant intervals of time. The like effect was experienced in incruſtations, and is mentioned in page 114.

[27] To what I have ſaid on this ſubject in page 124, I muſt add that, in my experiments, mortar made with terras powder, in the uſual method, does not appear to form ſo ſtrong a cement for water fences, as that made according to the ſpecification, with coarſe ſand; and I ſee no more reaſon for avoiding the uſe of ſand in terras mortar, than there would be for rejecting ſtone from the embankment. The bone-aſhes meant in this place are the dark grey or black ſort. I am not yet fully ſatisfied about the operation of them in this inſtance.

" quantity

" quantity of bone aſhes are to be omitted;
" and in the place thereof an equal meaſure
" of powdered terras is to be uſed; and if
" the ſand employed be not of the coarſeſt
" ſort, more terras muſt be added, ſo that
" the terras ſhall be by weight one ſixth part
" of the weight of the ſand.

" When ſuch a cement is required of the
" fineſt grain[28] or in a fluid form, ſo that
" it may be applied with a bruſh, flint pow-
" der, or the powder of any quartoſe or hard
" earthy ſubſtance may be uſed in the place
" of ſand, but in a quantity ſmaller as the
" flint or other powder is finer; ſo that the

[28] The qualities and uſes of ſuch fine calcareous cement are ſet forth in the thirteenth and twentieth ſections. They are recommended chiefly for the purpoſe of ſmoothing and finiſhing the ſtronger cruſtaceous works, or for waſhing walls to a lively and uniform colour. For this laſt intention, the mixture muſt be as thin as new cream, and laid on briſkly with a bruſh, in dry weather; and a thick and durable coat is to be made by repeated waſhing, but is not to be attempted by uſing a thicker liquor; for the coat made with this laſt is apt to ſcale, whilſt the former endures the weather much longer than any other thin calcareous covering that has been applied in this way. Fine yellow ochre is the cheapeſt colouring ingredient for ſuch a waſh, when it is required to imitate Bath ſtone, or the warm-white ſtones.

" flint powder or other ſuch powder ſhall not
" be more than ſix times the weight of the
" lime, nor leſs than four times its weight.
" The greater the quantity of lime within
" theſe limits, the more will the cement be
" liable to crack by quick drying, and vice
" verſa.

" WHERE ſuch ſand as I prefer cannot be
" conveniently procured, or where ſand can-
" not be conveniently waſhed and ſorted,
" that ſand which moſt reſembles the mix-
" ture of coarſe and fine ſand above pre-
" ſcribed, may be uſed as I have directed,
" provided due attention is paid to the quan-
" tity of the lime, which is to be the
" greater [29] as the ſand is the finer and vice
" verſa.

" WHERE ſand cannot be eaſily pro-
" cured, any durable ſtoney body, or baked
" earth groſly powdered [30] and ſorted nearly
" to

[29] FURTHER inſtructions may be gathered from the thir-teenth ſection. If ſea ſand be well waſhed in freſh water, it is as good as any other *round* ſand.

[30] THE cement made with theſe and the proper quantities of purified lime and lime-water, are inferior to the beſt, as the

" to the ſizes above preſcribed for ſand, may " be uſed in the place of ſand, meaſure for " meaſure, but not weight for weight, un- " leſs ſuch groſs powder be as heavy ſpe- " cifically as ſand.

" SAND may be cleanſed from every ſofter " lighter and leſs durable matter and from " that part of the ſand which is too fine, by " various methods preferable[31] in certain " circumſtances, to that which I have de- " ſcribed.

" WATER may be found naturally free from " fixable gas ſelenite or clay: ſuch water may, " without any notable inconvenience, be uſed " in the place of the cementing liquor; and " water approaching this ſtate will not re- " quire ſo much lime as I have ordered, to

the grains of theſe powders are more periſhable and brittle than thoſe of ſand. They will not therefore be employed, unleſs for the ſake of evaſion, or for want of ſand: in this latter caſe the finer powder ought to be waſhed away.

[31] THIS and the next paragraph is inſerted with a view to evaſions, as well as to ſuggeſt the eaſier and cheaper methods which may be adopted in certain circumſtances, by artiſts who underſtand the principles which I have endeavoured to teach.

" make

" make the cementing liquor; and a cement-
" ing liquor ſufficiently uſeful may be made
" by various methods of mixing lime and
" water in the deſcribed proportions, or
" nearly ſo.

" WHEN ſtone lime cannot be procured,
" chalk lime or ſhell lime which beſt re-
" ſembles ſtone lime, in the characters above
" written of lime, may be uſed in the manner
" deſcribed, except that [32] fourteen pounds
" and a half of chalk lime will be required in
" the place of fourteen pounds of ſtone lime.
" The proportion of lime which I have pre-
" ſcribed above may be encreaſed without
" inconvenience, when the cement or ſtucco
" is to be applied where it is not liable to
" dry quickly; and in the contrary circum-
" ſtance this proportion may be diminiſhed;
" and the defect of lime in quantity or
" quality may be very advantageouſly ſup-

[32] THIS relates to chalk lime burned with a ſufficient quantity of fuel in kilns of the common conſtruction. Chalk lime prepared as I ſhall ſhew in the next ſection, will go as far as ſtone lime, if not farther.

" plied

" plied ", by causing a considerable quantity " of the cementing liquor to soak into the " work, in successive portions and at distant " intervals of time, so that the calcareous " matter of the cementing liquor, and the " matter attracted from the open air, may " fill and strengthen the work.

" THE powder of almost every well " dried or burnt animal substance may be " used instead of bone-ash; and several " earthy powders, especially the micaceous " and the metallic; and the elixated ashes " of divers vegetables whose earth will not " burn to lime; and the ashes of mineral " fuel, which are of the calcareous kind, but " will not burn to lime; will answer the ends " of bone-ash in some degree [14].

[13] THIS practice is noticed, as the remedy which may be used for the defects arising from evasive measures, and as the method of giving spongy incrustations containing bone-ashes, the greatest degree of hardness.

[14] The useful substitutes for bone-ashes, have been treated of in the foregoing sections: the metallic micaceous and earthy powders are not recommended in the text, but only enumerated for reasons which influenced the style of this specification, and which lawyers will perceive.

" THE

" The quantity of bone-aſh deſcribed may " be leſſened without injuring the cement, in " thoſe circumſtances eſpecially which ad- " mit the quantity of lime to be leſſened, and " in thoſe wherein the cement is not liable " to dry quickly. And the art of remedying " the defects of lime may be advantageouſly " practiſed to ſupply the deficiency of bone- " aſh, eſpecially in building and in making " artificial ſtone with this cement,

" N. B. For inſide work, the admixture " of hair with this cement is uſeful.

" In witneſs whereof I the ſaid B. H. &c."

The excellence of my cement depends firſt, on the figure ſize and purity of the ſand; ſecondly on the purity of the lime, obtained in the choice of lime-ſtone, and in the perfect burning, and ſecured in the preſervation of it from air, in my method of ſlaking, and in the ſeparation of heterogeneous parts; thirdly on the uſe of ſtrong and pure lime water in the place of common water; fourthly on the proportion of ſands lime water and lime; fifthly, on the manner of mixing them; ſixthly, on the knowledge of ingre-

dients

dients and circumſtances which are injurious or uſeful; ſeventhly, on the uſe of bone-aſhes of determinate ſize; eighthly, on the art of ſuiting ſome of theſe to the ſeveral purpoſes; and finally on ſo many other particulars, as render it very difficult to give a more candid ſpecification, in the uſual compaſs, than this which I have enrolled, or to guard otherwiſe againſt evaſions, than by anticipating them.

I DO not think it neceſſary to inſiſt more minutely on the mechanical arts of applying the coarſer or finer calcareous cement, to produce the moſt agreeable effects, becauſe they are known to ſo many workmen employed under Meſſ. Wyatt, and are ſo nearly related to thoſe already known to the plaiſterers, that they are not likely to be miſſed or loſt.

SECTION

SECTION XXIV.

Experimental Compariſons of Chalk-Lime with Stone-Lime. Advices to the Manufacturers of Chalk-Lime, concerning the Art of rendering it equal, if not ſuperior, to Stone-Lime, for the Purpoſes of Builders Soap-Boilers and Sugar-Bakers.

ALL the authors whom I have conſulted, who have treated of cementitious buildings and of lime, from the time of Vitruvius, who wrote on theſe ſubjects in the reign of the Roman Emperor Titus or before it, down to the preſent hour; and all the artiſts with whom I have converſed, agree in the opinion that lime prepared from the cloſeſt lime-ſtone makes a ſtronger cement than that which is made of ſpongy lime-ſtone, and that the lime of chalk particularly, is incapable of acting as effectually as the beſt ſtone lime, in cementitious works or incruſtations which are expoſed to the weather.

THIS

This univerſal and unqueſtioned notion had great influence with me in the courſe of my experiments, until I had diſcovered not only the fallacy of it, but the grounds which gave riſe to it: both which I ſhall now expoſe, in the pleaſing hope of rendering great ſervices to many of my friends, and all who are proprietors of chalk-pits, or are obliged to uſe chalk-lime in their buildings.

The experiments already mentioned afforded me a great many opportunities of comparing cements made with lime and ſand, or with theſe and other ingredients in various proportions, and differing only in the kind of lime. In theſe compariſons I could not perceive that chalk lime, judiciouſly prepared and uſed, was in any reſpect inferior to the beſt ſtone lime: but I did not content myſelf with theſe. I made a great number of cements, with the ſole view of collating the reſpective merits of theſe kinds of lime, in ſmall and great incruſtations, in maſſes made to reſemble cut ſtone, in all expoſures and ſeaſons of the year; and after the ſtricteſt compariſons of thoſe which contained lime in equal quantities and were treated alike

alike in all reſpects; I was thoroughly convinced that my chalk lime was as good for any purpoſe of this kind, as the beſt ſtone lime in this kingdom; for I uſed the well-burned lime of Plymouth ſtone, which I reckon among the moſt excellent of our lime ſtones.

PLYMOUTH lime-ſtone looſes ſeven ſixteenths of its weight, in the converſion to lime, and becomes as white as chalk. Chalk looſes a little more in the perfect burning. Plymouth lime leaves a ſmall gypſeous reſidue in the ſolution preſcribed in the tenth page, which is preferable to that directed in the ſpecification: chalk-lime leaves none. Therefore the chalk-lime chemically or technically tried, appears to be equal, if not ſuperior to ſtone lime, in its cementing powers, when it is properly uſed.

THE prejudices entertained againſt chalk-lime may be traced to three ſources. The firſt is that which is mentioned in the fourth ſection. The vulgar criterion of the due preparation of lime conſiſts in the ſlaking: and as chalk, which has undergone a ſlight calcination

nation and thereby loſt only a part of its acidulous gas, is capable of ſlaking, by reaſon of its ſpongineſs; the manufacturers of chalk lime, content themſelves with the degree of calcination which renders it tractable or vendible, and thus bring it into diſrepute.

The ſecond ſource is mentioned in the fifth ſection. Chalk lime imbibes acidulous gas, during its expoſure to the air, much faſter than ſtone lime, and is conſequently more impaired or worſe, at the time of uſing it in mortar, than ſtone lime kept in the ſame circumſtances. As the lime may be greatly injured in this way, without ſlaking ſenſibly; and as there was no ſuſpicion or meaſure of ſuch injury, beyond what the ſlaking afforded; the acquired imperfection of chalk lime was conſidered as the very nature of it. In the thirtieth page it appears that a pound of chalk lime, placed in the quieſcent air of a chamber, imbibes two ounces and a half of acidulous gas in two days, which is the ſhorteſt time in which lime is uſually expoſed, if we count from the moment of its being red hot to that of its being mixed in mortar, during which interval it is in the ſtate of abſorption.

The third ſource I have diſcovered in the ſtructure of lime kilns. The cavity of a lime-kiln has the figure of a truncated cone inverted. When the charge, conſiſting of lime ſtone and fuel alternately ſtratified, has burned for ſome time, the fuel is exhauſted at the lower narrow extremity of the cavity, the lime in this part cools, and ſerves as a grate to the fuel and limeſtone above it, which continue to burn briſkly, for eighteen hours or longer, after the lime beneath begins to cool. During this time the laſt-mentioned part of the lime is expoſed to a ſtrong current of air; and the whole charge of lime ſtands in the like current of air until the kiln is cooled, or the lime is withdrawn; which in common practice is ſeldom or never done before the ſixtieth or ſeventieth hour after the combuſtion of the fuel commenced.

The injury which lime ſtone ſuſtains, in theſe circumſtances, which I have often imitated in my elaboratory, is not great; becauſe this lime is much more compact than the chalk lime. But when we obſerve that the beſt pieces of chalk lime of the common kilns,

and

and thoſe, which, after heating them ſufficiently, I had left in the fire-place, expoſed as they are in the uſual proceſs, are always efferveſcent; that good chalk lime, in a weaker current of air, imbibes more than three ounces of acidulous gas into each pound of it, in two days, according to the experiment of the thirtieth ſection; and that my chalk lime, which I remove from the fire-place as ſoon as it is ſufficiently burned, is perfectly non efferveſcent; we find that the long experienced imperfections of freſh chalk lime are owing more, to the faulty conſtruction of the kilns, and the ignorance of the manufacturer, than to any incapacity of chalk to yield excellent lime.

The means of preparing chalk lime to equal or exceed ſtone lime, and of making the beſt ſtone lime, may be gathered from what I have ſaid, and the following intimations. The kilns are to be made broader and ſhallower in the cavity which receives the charge: the circular wall incloſing this cavity, is to be continued tapering upwards, until it terminates in a lofty flue, in order to accelerate the combuſtion and increaſe the heat by a

quick current of air to be regulated by opening or closing the door-way, which is to be left in the circular wall at a convenient height for the introduction of the charge. The massive walls of the lower cone are to be lined with fire brick or apyrous stone set in the best fire loam; and are to be girded with iron. The fuel is to be so stratified with the lime stone or chalk, and the combustion is to be so conducted, that every part of the charge shall be sufficiently ventilated and heated, and that the lowest shall remain red hot until the whole is well burned. Then the current of air through the kiln is to be stopped, by closing the apertures at the bottom; or the red hot lime is to be removed out of it, to cool in quiescent air, until it is fit to be inclosed in air-tight vessels. A cask of chalk lime is not to be opened until the moment when the workman is ready to slake the lime; and the greatest expedition is to be used in the slaking, in making the mortar, and in applying it to use. By this treatment the chalk lime will answer every end of the best stone lime; and stone lime may be prepared and preserved in the highest perfection which the nature of the lime stone can admit.

THE

THE manufacturer of chalk lime who firſt adopts theſe meaſures near London will profit by them: for good lime is not only better, but goes farther in building, than bad lime; good chalk lime will anſwer the purpoſes of the ſoap-boiler, in half the quantity which they uſe of common chalk lime, the greater part of which ſerves only to waſte their lees and clog their vatts; and our ſugar-bakers will not heſitate about the price of good chalk lime, when they find that it is totally ſoluble in pure water, and introduces no ſelenitic matter into the ſugar. The exportation of lime to the Weſt India Iſlands will be a further incitement towards the improvements which I have ſuggeſted, when the planters receive the information which I intend ſoon to give them, concerning the principles by which *lime, duly adminiſtered facilitates, but injudiciouſly uſed impedes the granulation* of the ſaccharine part of their cane juice.

SECTION XXV.

Directions to the Houſes already ſtuccoed with the new Cement. Obſervations on the Objections of certain Artiſts; on the cementitious Works of the Romans; on the experienced and unequalled Duration of ſuch Cements; on the Cements of Loriot and others; and on certain Uſes of the Author's Cement.

THE inexperience of the workmen, their obſtinate adherence to their own notions, and the opinion which they entertained that ſome of the rules preſcribed to them were inſiſted on rather through an affectation of myſtery than for any uſeful purpoſe, operated ſtrongly againſt the beſt endeavours of Meſſieurs Wyatt, in the incruſtations firſt made on the great ſcale for uſe or ornament. In conſequence of theſe diſadvantages, which will be obviated in future, their ſtucco, although it excels others beyond compariſon and is far from being periſhable, is not quite ſo hard as it might have been made. This I mention, leſt theſe incruſtations ſhould be

be miſtaken for the beſt, which I have repreſented as exceeding Portland ſtone in hardneſs. Theſe laſt demand a ſtrict obſervance of the foregoing precepts reſpecting the ſeaſon and the expoſure as well as the materials and mechanical application of them.

The houſes which have been ſtuccoed with this cement are the following:

The north front of Mr. Delme's houſe on the ſouth ſide of Groſvenor-Square, ſtuccoed in November and December 1778.

The north and ſouth fronts of Mr. Viner's houſe in Conduit-Street, Hanover-Square, and the moulded walls of the area behind it, ſtuccoed in the ſummer and autumn of 1779: the fore-front repreſenting Bath ſtone, the other front and the walls and mouldings of the area, cloſely imitating Portland ſtone.

Mr. Bond Hopkins's houſe at Wimbledon in Surry, ſtuccoed in the ſummer of 1779, in every aſpect.

Mr. Birch's houſe at Hamſtead near Birmingham, ſtuccoed in autumn 1779, in every aſpect.

THESE were done under the direction of Mr. James Wyatt.

I MUST obſerve that the diſcoloured ſummit of the front of Mr. Viner's houſe, is natural ſtone; and that our cement never changes its colour, like thoſe which contain white lead or oil. This houſe ſeems to be well finiſhed. But when an incruſtation is made in an improper ſeaſon; when the parapet or gutters are defective, and the rain is ſuffered to penetrate through the ſpongy bricks and recent ſtucco; it is the fault of the workman and not of the cement, if the damp appears in the incruſtation of the attic ſtory, or if this part of it ſhould never harden compleatly.

I HAVE not yet been informed of the work done by Mr. Samuel Wyatt, except the ſtuccoing of the Honourable Juſtice Willes's houſe at Little Grove Eaſt Barnet, on the northern ſouthern and eaſtern ſides, in September and October 1779; and a piece of incruſtation repreſenting a very coarſe ſtone, made in November 1778, from the foundation

to

to the height of the cellar ſtory, on the eaſtern wall of Mr. Curzon's houſe in Davies-Street Groſvenor-Square. The earth had lain againſt this wall for many years: it was ſtuccoed immediately after the area had been opened to it, and whilſt it was damp; and by the miſtake of the painter, the ſtucco was painted whilſt it was freſh: I have not ſeen it ſince: but I am told that under all theſe diſadvantages it is incomparably better than the piece of common ſtucco which meets it from above.

WHAT has been fairly ſhewn of the cement, in this public manner, has given greater ſatisfaction; and Meſſrs. Wyatt are engaged to ſtucco a great number of capital houſes with it next ſummer. Theſe will be done in the higheſt perfection, becauſe the workmen are now compliant and experienced.

AN impediment however ſtill ſubſiſts to obſtruct the progreſs of this art in the public eſtimation. Some intereſted perſons diligently inſinuate that this cement has not the ſanction of long experience; and that however promiſing it now appears, it may moulder like others in a few years hence: they likewiſe obſerve that only a ſuperficial cruſt of

the

the above-mentioned ſtuccoes is ſufficiently hard, but that the internal parts may eaſily be cut or broke: and they repreſent the cement as an expenſive compoſition.

This publication, which ſhews it to be made of clean ſorted ſands, of bone-aſhes, and of good lime in about half the quantity uſed in the common method of making mortar, renders an anſwer to the laſt-mentioned objection quite unneceſſary.

The ſecond objection may be thus conſidered. The ſame attractive power, which draws acidulous gas from the air into lime, muſt neceſſarily prevent any conſiderable quantity of the gas from entering deeply in a recent incruſtation, until the lime at the ſurface is ſaturated with it, and conſequently until a ſuperficial layer of the cement is highly indurated. The ſame matter, which during its acceſſion hardens this part, muſt likewiſe tend to render it cloſer in the texture and leſs freely pervious to that which is ſtill neceſſary for the induration of the internal portions: and thus it happens that an incruſtation grows harder at the ſurface, in one week,

week, than it does deeply in the ſubſtance, in a year, although bone-aſhes be uſed to leſſen the obſtruction of the ſurface. Since therefore we know the reaſon why the interior parts of an incruſtation cannot harden in a much longer time than is neceſſary for the hardening of the exterior; ſince the materials of the cement are the ſame in the central parts as well as at the ſuperfices, and muſt be equally affected by acidulous gas when it can reach to them; ſince by our experience of old cements compoſed of lime and ſand, we know that the induration extends equally through the maſs of them, in the courſe of years; it is manifeſt that our ſtucco will harden in due time through the whole ſubſtance of it, as much as it does in a ſhorter time at the ſurface, and that the objection, founded on the internal weakneſs noticed in the firſt year, is futile.

To prove this by experiment, ſcrape away the hardened ſuperficial ſtratum, as I have often done; and taking care to bruſh off all that you have looſened beneath, leave the new ſurface of the friable part of the cement expoſed to the air for a few weeks. You will find

find it to harden like the firſt ſurface, whilſt the parts beneath it ſtill continue brittle. You will perceive after a repetition of the like experiment in the ſame place, that every part of the ſtucco is capable of acquiring the hardneſs of the firſt ſurface, in a few days, and conſequently that the whole will accquire it in the longer time neceſſary for the entrance of acidulous gas through the compact exterior cruſt.

With regard to the objections grounded on our ſhort experience of this cement, I think they can have very little influence amongſt informed men who know, from the writings of the antients, by the inſpection of old cements, and by the analyſis of them, that mortar made of lime and ſand can endure every trial of the weather in the moſt expoſed ſituations for a thouſand years or more. Such objections deſerve no better anſwer than ought to be given to an illiterate London bricklayer, who ſhould object to the uſe of porphyry in building, becauſe he has no certainty of its being ſo durable as the bricks

bricks which he had for many years experienced.

I AM aware of the opinion, which is prevalent at this time, that the antients uſed ſomething which is unknown to us in their mortar, and that this long loſt ingredient is the cauſe of the duration and hardneſs of thoſe cements which we ſo much admire in ſome of their ſtructures. A notion founded on conjecture does not demand a ſerious diſcuſſion. I will therefore treat it as a ſubject of converſation rather than of argument.

VITRUVIUS in the fifth chapter of the ſecond book of his architecture ſpeaks thus of lime.

Quare autem cum recipit aquam, & arenam calx, tunc confirmat ſtructuram, hæc eſſe cauſa videtur, quod e principiis uti cætera corpora, ita & ſaxa ſunt temperata: & quæ plus habent aeris, ſunt tenera: quæ aquæ, lenta ſunt ab humore: quæ terræ, dura: quæ ignis, fragiliora. Itaque ex his ſaxa, ſi antequam coquantur, contuſa minute, mixtaque arenæ conjiciantur in ſtructuram, nec ſolideſcunt, nec eam poterunt continere: cum vero

conjecta

conjecta in fornacem, ignis vehementi fervore correpta, amiserint pristinæ soliditatis virtutem, tunc exustis, atque exhaustis eorum viribus, relinquuntur patentibus foraminibus, & inanibus: ergo liquor, qui est in ejus lapidis corpore, & aer cum exhaustus, & ereptus fuerit, habueritque in se residuum calorem latentem, intinctus in aqua prius, quam exeat ignis, vim recipit, & humore penetrante in foraminum raritates conferveſcit, & ita refrigeratus rejicit ex calcis corpore fervorem. Ideo autem quo pondere saxa conjiciuntur in fornacem, cum eximuntur, non possunt ad id respondere, sed cum expenduntur, eadem magnitudine permanente, excocto liquore circiter tertia parte ponderis imminuta esse inveniuntur. Igitur cum patent foramina eorum, & raritates, arenæ mixtionem in se corripiunt, & ita cohæreſcunt, ficceſcendoque cum cæmenis coeunt, & efficiunt structurarum soliditatem.

The same ignorance of the nature of lime is betrayed by Alberti and later writers. And since we do not find any scientific rules prescribed by literary artists, for the composition of calcareous cements with such chosen and sorted materials as I have described, or in such proportions of them; and since it is highly improbable that the remembrance

membrance of an uſeful ingredient, or any knowledge once accquired in an art practiſed in ſo many countries nd by ſo many different perſons in every age, ſhould have been loſt; we have the moſt ſatifactory reaſons for concluding that the antients had no ſkill beyond that of our modern builders, in the preparation of lime or mortar.

The ruins of Herculaneum, and other reliques of their works, furniſh us with abundance of bad mortar and defective incruſtations, which are inſtances of their ignorance of thoſe principles by which the beſt cement might be made equally cheap. The total ruin and obliteration of many of their buildings, argue to the ſame end; for well cemented works ſuffer very little by dilapidation, by reaſon of the difficulty and expence of pulling them to pieces and applying the materials to other ſtructures. If to theſe conſiderations I can add an expoſition of the fortuitous circumſtances which rendered ſome of their cements uncommonly hard and durable, I hope I ſhall not be ſuſpected of ungenerous invidious motives, in ſaying that the aqueducts and other ſtructures, which

which have been preſerved to us through ſo many ages, by the ſtrength of their cement, are monuments rather of the good luck, than of any extraordinary ſkill, of thoſe who built them.

When the neighbouring quarries afforded good lime ſtone, free from gypſum, and ſuch as required to be well burned before it could ſlake freely; when the preparation of the lime, at the public expence, afforded no temptation for parſimony in fuel; and when the vicinity of the lime ſtone, and the quick conſumption of the lime in great maſſive works, prevented thoſe injuries which it ſuſtains in long tranſportation and expoſure, in the ſlaking of great quantities of it at once, or in the keeping of mortar made with it; the ignorance of the artiſts could not produce any defects dependent on bad lime, becauſe neceſſity or chance inforced all that could have been ſought by choice, in this inſtance.

When the vicinity afforded ſand, clean, quartoſe ſharp well fized and reſembling our mixture of the coarſe and fine; chance furniſhed

niſhed all that ſkill could aim at, in the choice and preparation of this article.

When walls of immenſe thickneſs were conſtructed chiefly with ſmall ſtones, in the way of boulder-work, the great conſumption of mortar made every practicable ſaving of lime an object of great importance; and as the mortar muſt be made ſtiff for ſuch work, it was neither convenient nor neceſſary to mix much lime in it, or to uſe fine ſand in it, or to exclude the rubble from it: and thus, by motives of œconomy and convenience, rather than by any others, they were led to the meaſures which inſured to the cement of ſuch ſtructures every perfection dependent on the goodneſs of lime and ſand and on good, if not the beſt, proportions of them.

When the ſtones uſed in building were recently dug, or collected from the beds of rivers, the artiſts needed no precautions againſt the bad effects of dry bibulous and duſty ſtones or bricks; and their works had, of neceſſity, every good quality attainable by the practice, which I commend, of ſoaking theſe materials. When their water was good,

the cement abounding in lime was not much the worſe for their ignorance of the uſe of lime water.

When the ſtructure was intended to ſtand by its own ſtrength, rather than to depend on timbers; and was by the ſolidity of its bearings and the diameter of its ſtoney ſubſtance, ſecured from agitation; when the thickneſs of the walls prevented the cement from being haſtily dried, and afterwards ſecured it from being thoroughly wetted; and when the enormous weight contributed to the approximation and coheſion of the parts of the cement to each other and to the ſtones; every defect of cementitious buildings, of a contrary deſcription, was obviated by the nature of the ſtructure, which rendered it as perfect, in the hands of any artiſts, as the moſt conſummate ſkill could make our modern ſlender tremulous bibulous walls.

In the concurrence of theſe circumſtances, we find excellent cements of great antiquity, which I need not point out to literary men: but ſince they are found no where elſe, that I have diſcovered; and ſince it is not probable that the antients had any art of this kind unknown

known to the moderns, I think I am authorized to conclude that their beſt cementitious works, inſtead of being held forth as inſtances of their unequalled ſkill, ought rather to be conſidered as ſubſtantial proofs of the duration of mortar or ſtucco duly compoſed of ſand and lime, beyond all others, and of the utility of theſe endeavours which I have made for preparing calcareous cements according to ſcientific principles, which enable us to make them in the higheſt perfection in all places, and to accommodate them to every purpoſe of uſe or ornament.

I HAVE ſtudiouſly avoided ſtrict compariſons of my cement or of the beſt Roman cements, with the oil cements; becauſe the beſt of theſe is private property; not doubting that my liberal readers will give this ſilence a conſtruction equally favourable to the proprietors and to me. But it is not neceſſary to lay myſelf under the ſame reſtraint reſpecting the reputed improvement of Monſieur Loriot, publiſhed in 1774 at Paris, in a pamphlet entitled, "A treatiſe on a new diſcovery in the "art of building, made by Monſieur Loriot, "mechanic and penſionary to the king; in

" which is announced, by order of his ma-
" jesty, the method of composing a cement
" or mortar fit for an infinity of works as
" well in building as in decoration."

THE first half of this essay serves only to display the sanguine hopes and lively imagination of the author, which transported him beyond the bounds of his knowledge in this subject, and all the rules of physical induction. In the thirty-first page he says that " the admixture of powdered quicklime, in " any mortar made whith flaked lime, is " the most effectual method of giving it " every desirable perfection; and that this " is the chief discovery which he announ-" ces." In the next page he gives the following prescription.

" TAKE one part of brick-dust finely sift-
" ed, two parts of fine river sand skreened,
" and as much old flaked lime as may be
" sufficient to form mortar with water, in
" the usual method, but so wet withal as to
" serve for the flaking of as much powdered
" quick-lime as amounts to one fourth of the
" whole quantity of brick-dust and sand.

" When

" When the materials are well mixed, em-
" ploy the compoſition quickly, as the
" ſmalleſt delay may render the application
" of it imperfect or impoſſible."

In the 40th page he ſays " Another me-
" thod of making the compoſition is, to
" make a mixture of the dry materials;
" that is to ſay, of the ſand brick-duſt and
" powdered quick-lime, in the preſcribed
" proportion; which mixture may be put
" in ſacks, each containing a quantity ſuf-
" ficient for one or two troughs of mortar.
" The abovementioned old ſlaked lime and
" water being prepared apart, the mixture
" is to be made, in the manner of plaiſter,
" in the inſtant when it is wanted, and even
" on the ſcaffold, and is to be well chafed
" with the trowel."

To expreſs Mr. Loriot's diſcovery briefly and diſpaſſionately, I would ſay, when an ignorant artiſt makes mortar with whiting inſtead of lime, he can mend it conſidera-bly by adding lime to it: but his mortar will ſtill be defective, in compariſon with the beſt that may be made, by reaſon of the

old ſlaked lime or whiting. For on repeated trials I found this to be the true ſtate of the caſe.

Lime ſuſtains leſs injury in powdering ſmall quantities of it in a covered veſſel, than by ſlaking, in the uſual method, with common water: and powdered lime, in the mixing of it with ſand and water, excites a warmth in the maſs, which greatly contributes to its drying or ſetting quickly. Mr. Loriot not knowing how to ſlake lime without impairing its cementing virtue, and taking the ſpeedy exſiccation as an omen of perfect induration, imagined the preſcription of powdered lime to be a great improvement.

If the powdering of lime, without expoſing it much to the air, were not an expenſive operation, I ſhould have directed this powder to be uſed inſtead of water-ſlaked lime, for thoſe parts of an *incruſtation*, which are prevented from drying in due time, by their vicinity to the damp earth or to projections on which the rain lodges. The cement to be applied in ſuch circumſtances ought,

ought, as I ſaid in the ſpecification, page 202, to contain more lime than I have preſcribed for other ſituations; and it will be found the better for being made with powdered quick-lime, becauſe it will dry the ſooner, and becoming pervious to air in conſequence of the exhalation of its water, it will more ſpeedily acquire that hardneſs which ſecures it from being exhauſted of the lime by the conſtant moiſture or the trickling rain.

The public are indebted to Mr. Hartley for the experimental proofs he has given of the efficacy of his method of ſecuring houſes from fire; and to lord Mahon for thoſe judicious and expenſive experiments by which he has ſhewn that a calcareous incruſtation anſwers the purpoſes of Mr. Hartley's art. I am afraid that their good intentions will be fruſtrated by the indifference of men to diſtant or improbable evils, and their diſlike to any immediate expence which affords no extemporary convenience or ornament. But altho' ſuch motives of œconomy ſhould diſſuade us from adopting their meaſures in the fulleſt extent, we ought certainly to avail ourſelves

ourſelves of the uſeful knowledge which they have imparted, ſo far as to prefer a ſafe and durable ſtucco, wherever it is applicable by the aſſiſtance of hair, before wainſcot or wooden ornaments. For although no metallic or calcareous covering can ſecure the wood of a houſe from being charred by a great fire, the danger of others is leſſened as the combuſtible materials are ſecured from the action of the air, and conſequently from contributing to the deflagration.

I have thought that the ſmall ſtones, which conſtitute the gravel choſen for our roads, could not be reduced to duſt ſo ſoon as they now are, by the heavy carriages, if they were firmly bedded in a ſmall quantity of coarſe and good calcareous cement, ſo that the bodies which roll over them ſhould rather compreſs them, than grind them againſt each other as they do at preſent. And as the frequent failures of pavement are manifeſtly owing to the infirmneſs of the ground and the looſeneſs of the ſtones, I have imagined that a ſolid bed of cementitious work, in the manner of the Romans, and the ſetting of the paving ſtones in good mortar,

mortar, would ultimately leſſen rather than enhance the expence. I offer theſe conjectures in the hope, that no body will preſume to decide on the ſubject, who does not know the difference between the common mortar, and the beſt that can be made of lime and ſand; and that ſome public-ſpirited man will make the experiment, where lime is cheap and the expence of pavement or of gravel is conſiderable. If the expence ſhould be found too great for any public works of this kind, the ſame meaſures may nevertheleſs be tried in private areas and walks, in which the neatneſs, duration, and prevention of vegetation, may compenſate for the extraordinary price.

THE END.